ALLTEM System User's Manual
Munitions Management Projects

ESTCP Project MM-0809

ALLTEM Multi-Axis Electromagnetic
Induction System Demonstration and Validation

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EXECUTIVE SUMMARY

An advanced multi-axis electromagnetic induction system, ALLTEM, has been specifically designed and developed for detection and discrimination of unexploded ordnance (UXO) by the U.S. Geological Survey. This document is a combined user's manual for operating the ALLTEM including data acquisition with navigation, data pre-processing in a customized LabView interface, and finally data processing from within Geosoft Oasis Montaj.

This ALLTEM software manual is a supplement to the on-line tutorials and help files that are in each software program. The on-line tutorials, simulators and help files should be sufficient for most purposes, but additional explanations and details are contained in this manual. This manual includes chapters for system nulling, data acquisition, a system nulling simulator, a data acquisition simulator, data preprocessing, data processing within Oasis Montaj, and using the dipole inversion program.

Accompanying this manual are ZIP files containing the acquisition and pre-processing LabView software and also data acquisition and calibration (nulling) software simulators that can be used offline for training. Installation instructions are also included in this manual for each of the software packages.

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1.0   INTRODUCTION

This ALLTEM software manual is a supplement to the on-line tutorials and help files that are in each software program. The on-line tutorials, simulators and help files should be sufficient for most purposes, but additional explanations and details are contained in this manual. This manual includes chapters for System Nulling, Data Acquisition, a System Nulling Simulator, a Data Acquisition Simulator, and the Data Preprocessing Program.

Installation steps for the ALLTEM Data Acquisition Simulator program are shown below. Installation for each of the ALLTEM software programs is similar. The procedure assumes that the user has a working knowledge of the Microsoft Windows operating system, particularly with regards to installing a program.

1.1   General Notes

Terminology used in this document:

1.1.1   Button controls

These are used for ON/OFF control of functions and may be:
- Oval shaped, containing an illuminated triangle indicator (bright green when ON),
- Rectangular/square shaped, (bright green when ON),
- Rectangular/square shaped with text inside the shape (i.e. START)

Some button controls will toggle ON to OFF with each click, others are a one time-momentary action (such as a one-time auto scale request), and may only flash to bright green for a very short time. Some controls may appear greyed out if the current state of the program does not allow selection of that function.

1.1.2   Box Controls

These are also used for ON/OFF control functions. When they are clicked, a "check" mark will appear in the box. These are toggle functions, and will remain in the state they were last clicked in.

1.1.3   Button Indicators

These are used for showing the ON/OFF state of a program variable. They are round and turn from grey to a bright color when ON. Clicking on them will not change their state.

1.1.4   Fields

These refer to areas in the screen which numeric or textual information is displayed. Fields which have a grey background color are for indication only. Fields with a white background are controls which may be changed by the user. Numeric controls have an up/down adjuster to the left of the field which may be used to change the value, or alternatively, the desired value may be

entered directly in the field. Text controls are either normal text entry fields, or enumerated controls. For enumerated text controls, the field will have an up/down adjuster to the left. This should be used to select the desired action (i.e. GPS Mode = RTK_FX, RTF_FL, SPS, DIFFER,…). Do not try to type the text into the text field, use the up/down adjuster.
1.1.5   Frame refers to graphic boxes around groups of controls or indicators on the screen. Some frames may have a textual title with them that describe the items in the group.

1.1.6   Icons

These refer to program controls which have a button containing a graphical picture (such as the RUN arrow icon on the top control bar which is used to start a program).

The revision level of programs shown in the screen shots appears in the top blue bar. Typically this is a number, i.e. _01, or a letter, i.e. _g. The text may refer to refer to revisions other than those in the screen shots. This discrepancy should be ignored.

1.2   Installing the ALLTEM Data Acquisition Simulator program

Place the "ALLTEM Data Acquisition Simulator.zip" file in the C:\ root drive.

Note: It is not necessary, but if you want the screens to match this document, install 7-Zip on your computer. The freely distributed installation file, "7z465.exe", is included in the ALLTEM Data Acquisition Simulator.zip file.

Use an un-zipping program (for example, WinZip, 7-Zip) to extract the files in the "ALLTEM Data Acquisition Simulator.zip" file. The following, or similar screen should appear: (figures 1.1 through 1.5 are screen shots from 7-Zip).
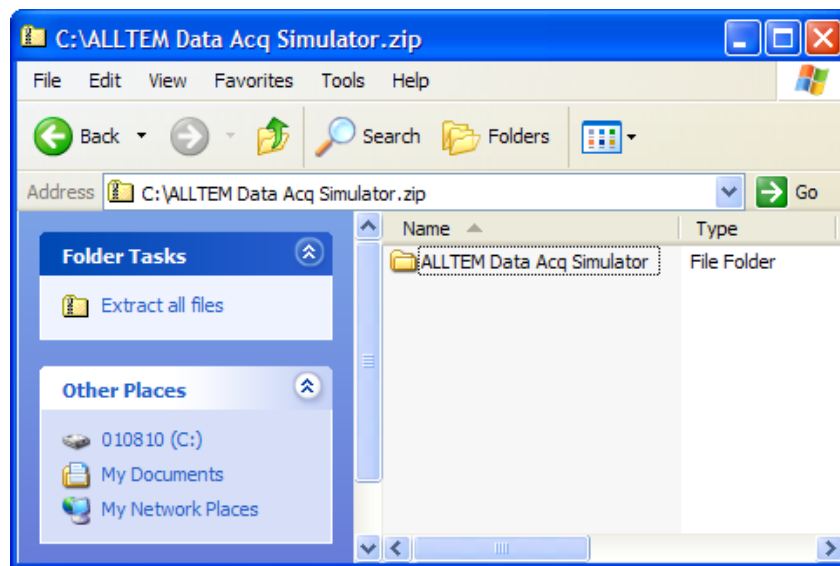
Figure 1.1. ALLTEM Data Acquisition Simulator Folder.

Click **Extract all files**. By default, a directory named "C:\ALLTEM Data Acquisition Simulator" will be created and the extracted files will be placed there. If you wish to choose a different destination, use the Windows browse button.
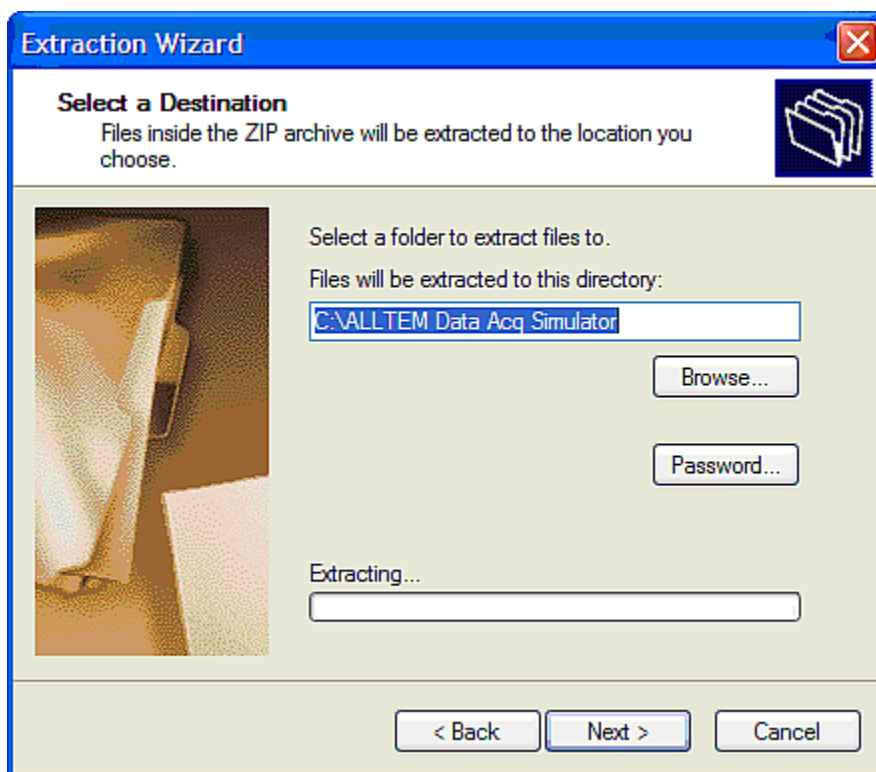
Figure 1.2. Select an extraction directory

Click **Next** to begin the extraction.
When finished, the contents of the ALLTEM Data Acquisition Simulator directory should look like Figure 1.3 (if the default directory was chosen):
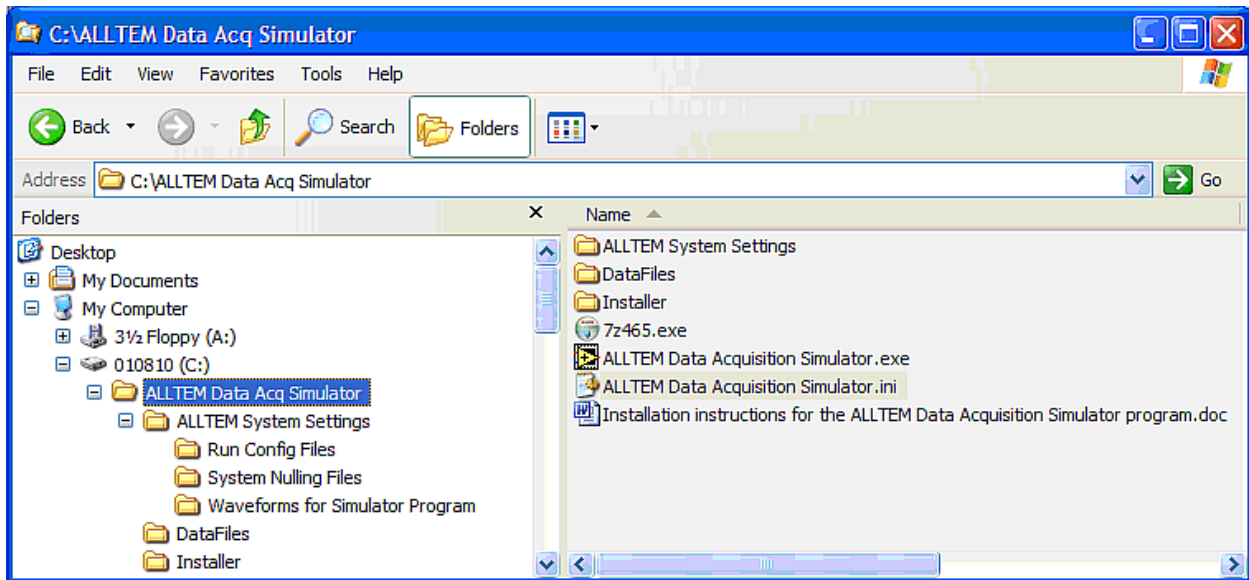
Figure 1.3. ALLTEM Data Acquisition Simulator Directory Screen.

Open the **Installer** folder and run **Setup.exe.** The following screen will appear.

Figure 1.4. Installation Wizard Screen.

Click **Next>**.

The program will be placed under the Program Files directory. If you want a different destination directory, use the **Browse** button.
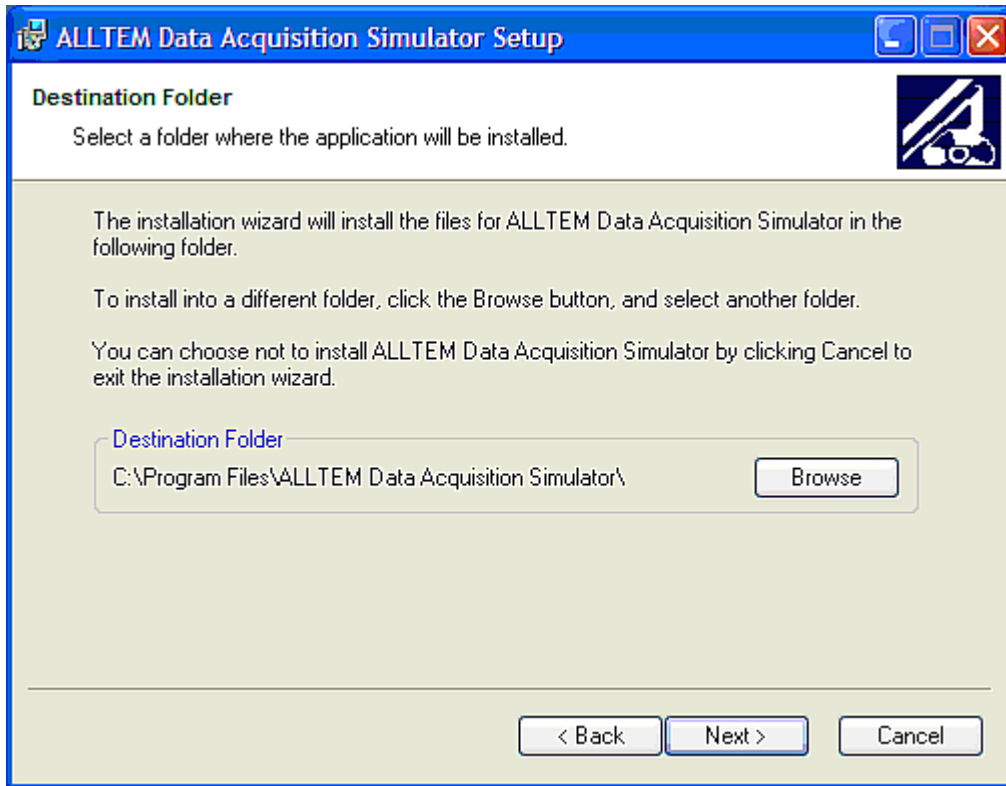
Figure 1.5. Example Destination Folder screen.

When finished, click **Next>**, and then **Next>** on the following screen to begin the installation. Allow the installation to complete. The application can be removed from the computer using the standard Add or Remove Programs in the Windows Control Panel.

2.0   NULLING CALIBRATION SOFTWARE

2.1   Purpose of Nulling

ALLTEM uses a continuous triangle current waveform in the transmitting (TX) coils. This current produces a "primary" magnetic field that induces currents and magnetic domain alignments in conductive and ferrous targets. However, the TX coil current also induces strong responses in the receiving (RX) coils. These "primary" responses are much stronger than the "secondary" responses from the targets of interest and must be eliminated in some fashion. This is accomplished in three ways: (1) The RX coils are in geometrically symmetric positions and the voltages from the RX coils are added with opposite polarities so that the primary voltages cancel; (2) Since mechanical positioning cannot be perfect, electronic balancing,or nulling, of the voltages from the various pairs of RX coils is applied. Electronic nulling uses trimming resistors. Most of these trimming resistors can be adjusted under software control. This is what the Nulling Software accomplishes. Although ALLTEM's response to earth conductivity is negligible, ALLTEM does respond to the magnetic permeability of the ground. Adjustments to reduce the earth's magnetic response is the second purpose for nulling; (3) Because the earth response will vary with location and with the cart's height and orientation with respect to the ground as it moves, and because thermal expansion and contraction of the cube and coils causes slow mechanical changes with temperature that unbalance the various coil pairs, the final step in removing unwanted signals is done in the preprocessing software, where the square wave offset voltages caused by these various sources are removed. However, electronic nulling needs to be done to prevent amplified difference voltages from getting too large or signals will begin to clip when amplifier or digitizer voltage limits are exceeded.

2.2   When to "Null" the ALTEM Receivers

Nulling should only be done when the following conditions are met:
- The cart is on its wheels on locally flat ground. Do not elevate or reduce the height of the cart or change its orientation which should be parallel to the ground.
- The ground should be free of metallic objects to a depth of about 3 m and no significant non-system above-ground metallic objects should be within about three meters of the cube. System metallic objects should be in their normal operating positions. These include: the global positioning system (GPS) antennas, the attitude and heading reference sensor (AHRS) unit, system cables (which should be dressed and in their normal operating positions), and the towing vehicle which should be connected to the tow bar and in its normal position with respect to the cart.
- **Important note: The system should be run for at least 15 minutes to allow electronic devices to thermally stabilize before going through the nulling procedure.**
- The nulling procedure must be done at the beginning of operations at any new site and should be checked daily and readjusted if necessary. Acceptable ranges of voltages are indicated on each virtual instrument meter and the adjusted values can be stored in a file to be used in all subsequent operations as will be discussed in more detail below.

2.3 Operation

To start the program, double click on the icon called "ALLTEM System Nulling."

Figure 2.1. Double click on this icon to launch the ALLTEM System Nulling program.

The first screen that will come up is called "SETUP BEFORE STARTING," Figure 2.2. At the top of the left frame is text that says, "Contents of C:\ALLTEM System Settings\System Nulling Files". Below this text is a list of nulling files with name, size, and date modified shown. Select the one you want to use and double-click on it. If you have not previously stored a nulling file and have no basis on which to select a file, select the "Default.nul" file. In this example a file called "Test.nul" is shown selected. This file contains a note in the **Nulling File Information** field. Later, when you store your own nulling file you will be presented with the option of entering a note regarding your nulling files should you choose to do so. Any note that you write will be stored as a header in your file and displayed, as shown here, when you open your file.
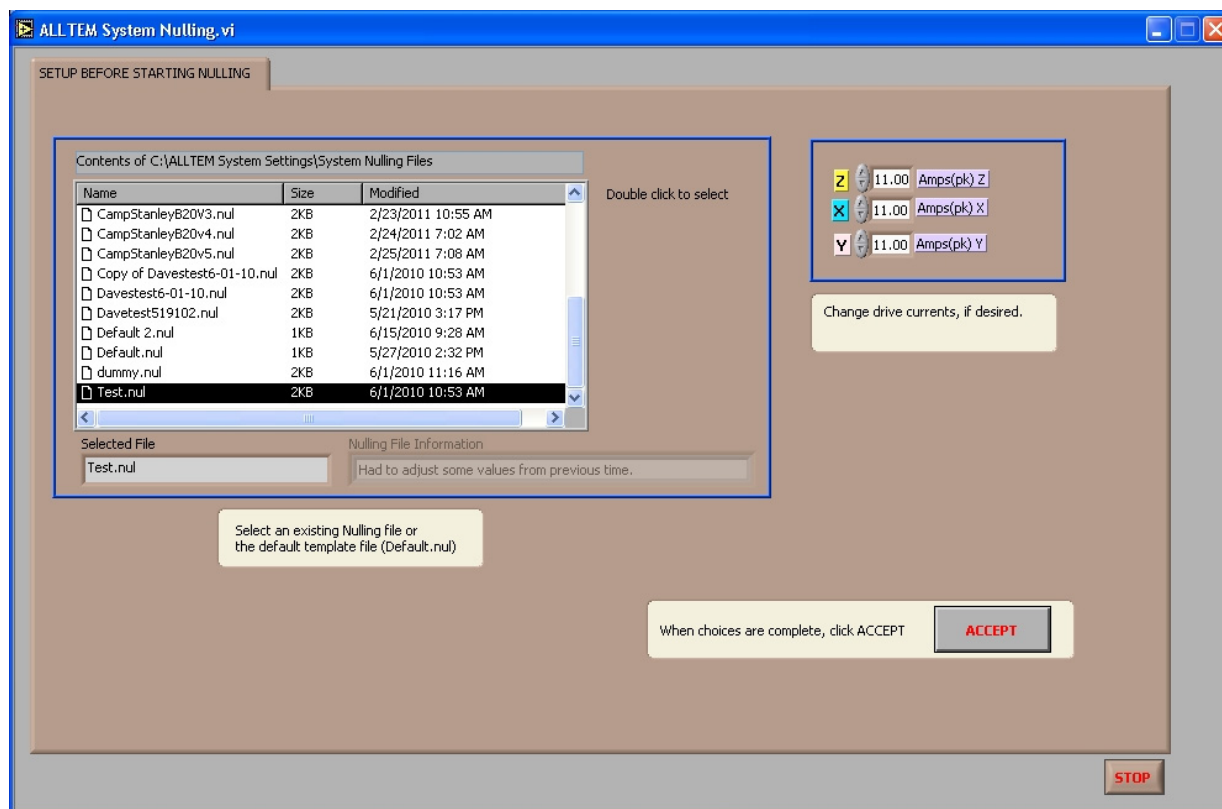
Figure 2.2. The "SETUP BEFORE STARTING NULLING" screen. Nulling file names, drive coil currents, and buttons to "ACCEPT" or "STOP" are shown.

The smaller frame in the upper right allows the option of changing the drive current peak amplitudes for each of the three orthogonal TX coils. The range is 0 to 11 amperes. The oval buttons can be clicked to adjust the current for the corresponding coil up or down in 1 A steps. Alternatively, a current value can be typed in any of the three windows. Normally, these currents will be left at their maximum settings. In rare circumstances it may not be possible to null the system at the maximum 11 A drive current, as when, for example, the current drive amplifier could clip or overheat in extremely hot conditions. We have successfully operated the system for extended periods at the maximum 11 A current in ambient temperatures up to 41 degrees C (106 degrees F).

After all selections are made, click on the **ACCEPT** button which will bring up the **SYSTEM NULLING** screen, Figure 2.3. This screen has three tabs, **SYSTEM NULLING** (the active screen in this figure), **SAVE**, and **NOTES**. The descriptions that follow will work through this screen in the order of the numbers indicated, which is also the order in which the program should be used, although some steps may be omitted if not needed. The frame at the left has a message field. This will be discussed in a later example and will contain information needed for certain combinations of TX coils and RX coils. At the lower left is a "**Block Diagram**" frame. This frame is for illustration only. No values can be entered or altered within this frame. Notes 1 and 3 can be found by clicking the **NOTES** tab. As discussed above, what is being done when nulling is that RX coil-pair relative gains and offsets are being adjusted to keep the differenced voltages from the various RX coil pairs within the maximum voltage ranges of the analog amplifiers and

digitizer input. Ideally, when the system is not over a target, the RX voltages for all polarities would be zero. The objective is to adjust the system so that all voltages are as close to zero as possible.

Step 1: Select a **DRIVE** coil to be used (the **Z**, **X**, or **Y** button). In this example the **Z** coil (the horizontal coil that produces a vertical magnetic field) is shown selected (illuminated button). These could be done in any order, but for simplicity it makes sense to select these from top to bottom, that is, do everything for the **Z**-polarization first, followed by the **X** and then the **Y** TX coils. It is always possible to come back to any particular combination of TX coils and RX coils again to double check the quality of the nulling.
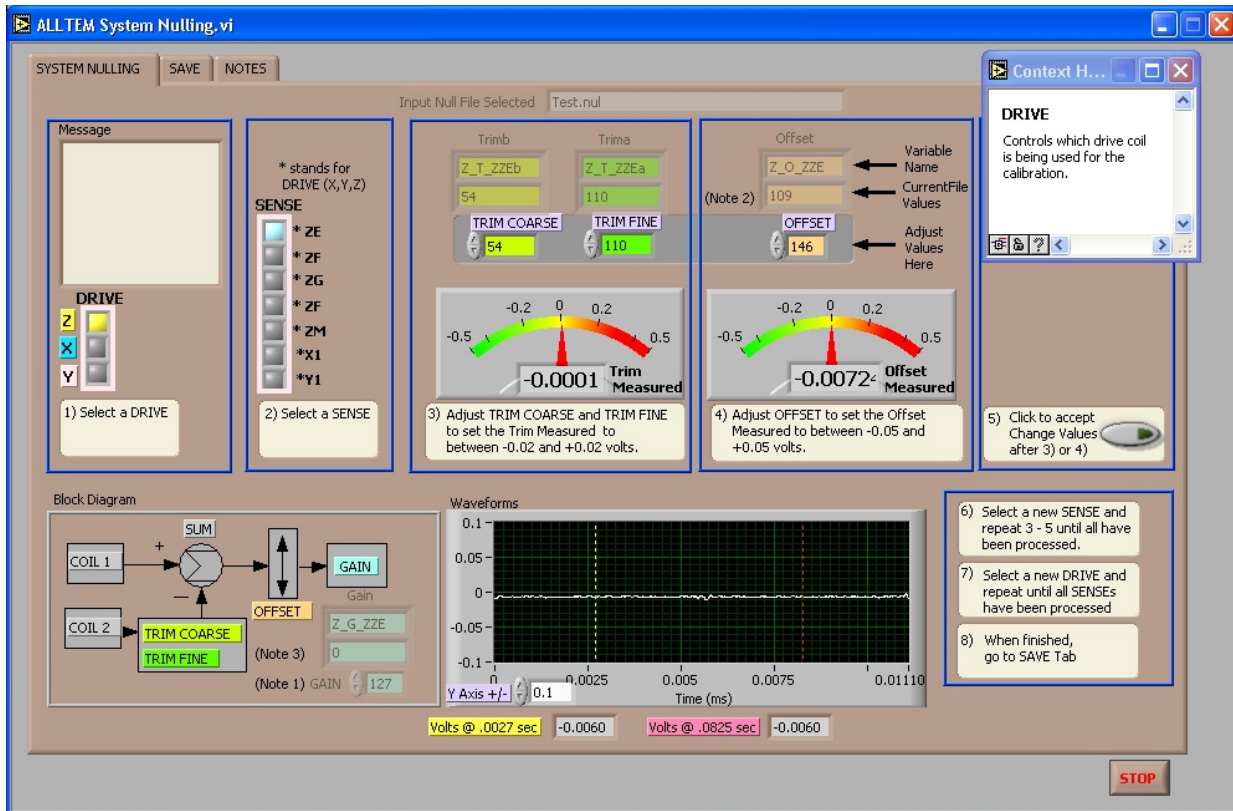
Figure 2.3. The **SYSTEM NULLING** screen where amplifier trims and offsets are selected. Context-sensitive help is available on screen (for example, the pop-up window in the upper right of the screen). Help notes are selected by moving the cursor to the area where help is desired. The help pop-ups may slow the program and after familiarization they may no longer be needed. They can be toggled "off" and "on" by using the CTRL-H key combination. Trim and offset parameters are annotated with black arrows.

Step 2: Select a **SENSE**. There is a column of 7 buttons corresponding to each of seven sense coil pairs. Multiplying by the three possible TX coil polarizations gives 21 possible combinations. Not all of these are useful. The names and configurations of the polarizations used are shown in the ALLTEM system hardware manual. When a combination is selected that is not used, a message will appear in the message box stating that this combination is not used and no

attempt should be made to adjust it. Another possible message is that the particular case cannot be adjusted electronically and a manual potentiometer must be used to make this adjustment. This case is discussed below. As with the TX coil buttons it makes sense to select these from top to bottom. It may be discovered that some polarizations are more prone to drift than others. After the first adjustment, any combination can be reselected and readjusted before saving the nulling file, and also on subsequent openings of that file. It is not necessary to always readjust all the polarities.

Step 3: Adjust **TRIM COARSE** and **TRIM FINE** using the up/down buttons to set the **Trim Measured** meter to between -0.02 and +0.02 volt. Simply click on the up-down buttons, first the coarse and then the fine, to bring the resulting voltage as close to zero as possible. The TRIM COARSE and TRIM FINE adjustments change the value of a digitally controllable potentiometers on the ALLTEM SumScaleFlt boards.

The potentiometer is in parallel with another resistor on the board. Because of this configuration, changes to the value of the digital potentiometer do not change the Trim values in a linear fashion. The Trim values near the top of the range (near 255) will not affect the Trim values as much as values near 0. A good technique is to place the TRIM FINE value near 100 and then adjust TRIM COARSE until the value in the Trim Measured meter just transitions from positive to negative or negative to positive values. Then, if necessary, adjust the TRIM FINE control to get the Tim Measured closer to zero. The selected values appear in fields for coarse and fine (54 and 110, respectively, in this example). The "Trim B" (coarse value) and "Trim A" (fine value) variable names that will be stored in the nulling file are shown in the top windows in this frame. As may be deduced, these variable names are descriptive. In this example "Z_T_ZZEb" indicates that the stored value contains information for the vertical polarization (Z) trim (T) using the particular ZZE TX/RX combination and that the value stored is a coarse "B" trim setting. This naming convention should not be altered.

Below the meters is a waveforms display panel. The waveform shown in the waveform display is the RX response during one cycle of the 90 Hz triangle coil drive signal (0.0111 ms). The two large "spikes" (one positive, and one negative) correspond to the two corners of the triangle wave cycle. All measurements made with the nulling program are made after the effects of the "spike" voltage have died out. Referring to the waveform display in Figure 2.3, the voltage shown in the **Trim Measured** meter is calculated by subtracting the waveform values at the yellow and pink cursor points from each other. The waveform in this graph was captured when the system coils drives were not active, so the waveform is not representative of an actual nulling condition. The value in the **Offset** meter is the value of the waveform voltage at the yellow cursor. The sensitivity on the voltage (vertical) scale can be selected with the **Y Axis** +/- button.

Step 4: This adjustment allows a voltage offset to be entered (see the block diagram). The resulting range after coarse and fine trim and voltage offset adjustments should lie between –0.05 and +0.05 volt, as indicated on the meter. As shown, it is often possible to get both the trim and offsets well within these maximum range limits.

Step 5: **NOTE!** The adjustments made in steps 3 and 4 will **not** be stored until the **Press to accept Change Values** button is clicked, so when the values you have for trim and offset are the best you can achieve, **click this button before going to the next sequence.**

Steps 6 and 7: Go through the sequence for all three TX coils and all seven RX coil pairs. There are some exceptional cases that will be flagged in the message box. We show an example in Figure 2.4. Notice the message in the **Message** box "ZX1 trim can't be set with the TRIM adjustment." This was an old message when the trimming had to be done using a mechanical potentiometer, R19, on the ALLTEM_SumScaleFlt printed wiring board (PWB). The ZY1 combination also required manual adjustment of a potentiometer, R129. The message also directs the user to the **NOTES** tab (Figure 2.5). This is now included just as reference information in case the potentiometers need to be manually adjusted. The combinations YX1 and XY1 are not meaningful and are automatically flagged.

Step 8: When all combinations have been nulled, go to the **SAVE** tab, Figure 2.6.

Step 9: Name the new nulling file. The "nul" file name extension is automatically appended to the name. A comment can also be included.

Step 10: The last step is to save the new nulling file by clicking the round button. **This must be done to save a new nulling file.**

This completes the procedure for adjusting voltage trims and offsets for all polarities. When the ALLTEM system is not available or cannot be operated, a simulation program is provided for training purposes, though it is always better to perform the procedure with the system running.
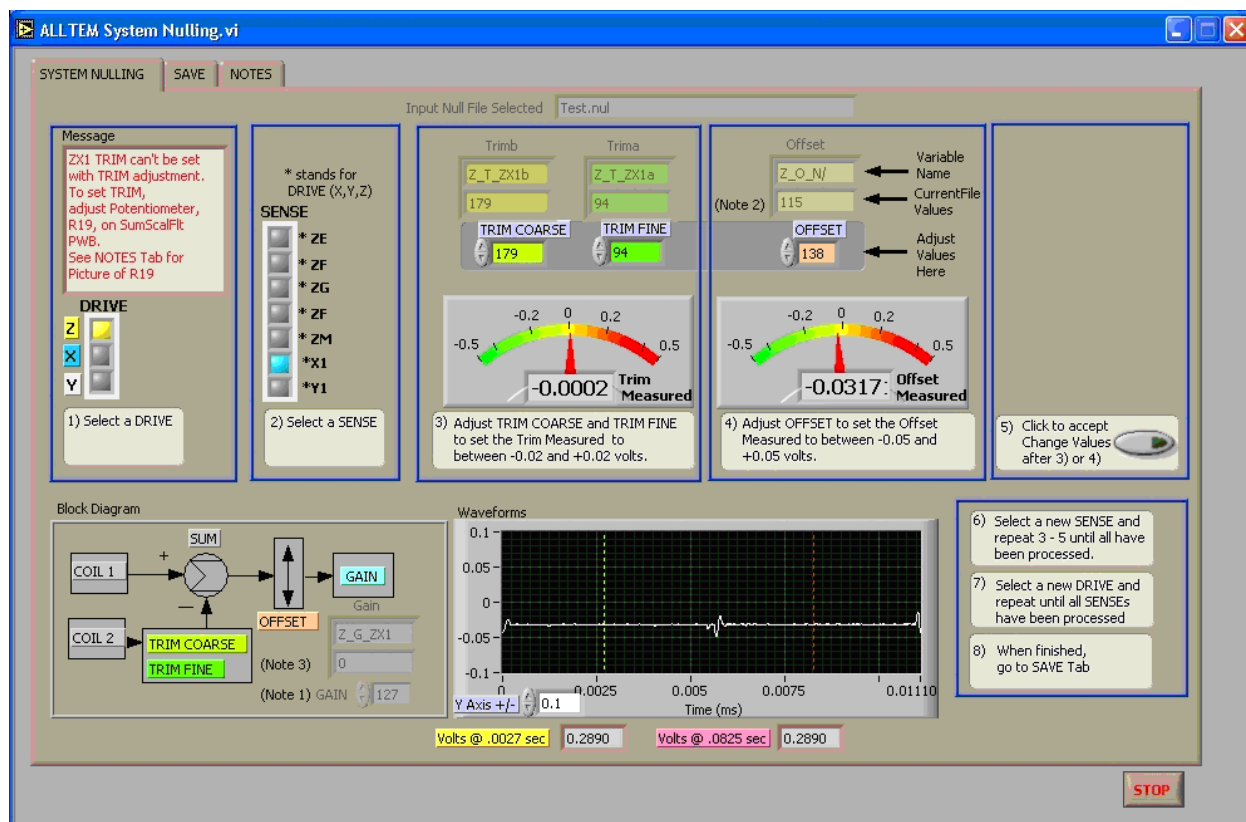
Figure 2.4. An old message indicating that the ZX1 TX/RX coil combination that cannot be adjusted electronically. This has since been resolved so that all receivers can be trimmed electronically through software.
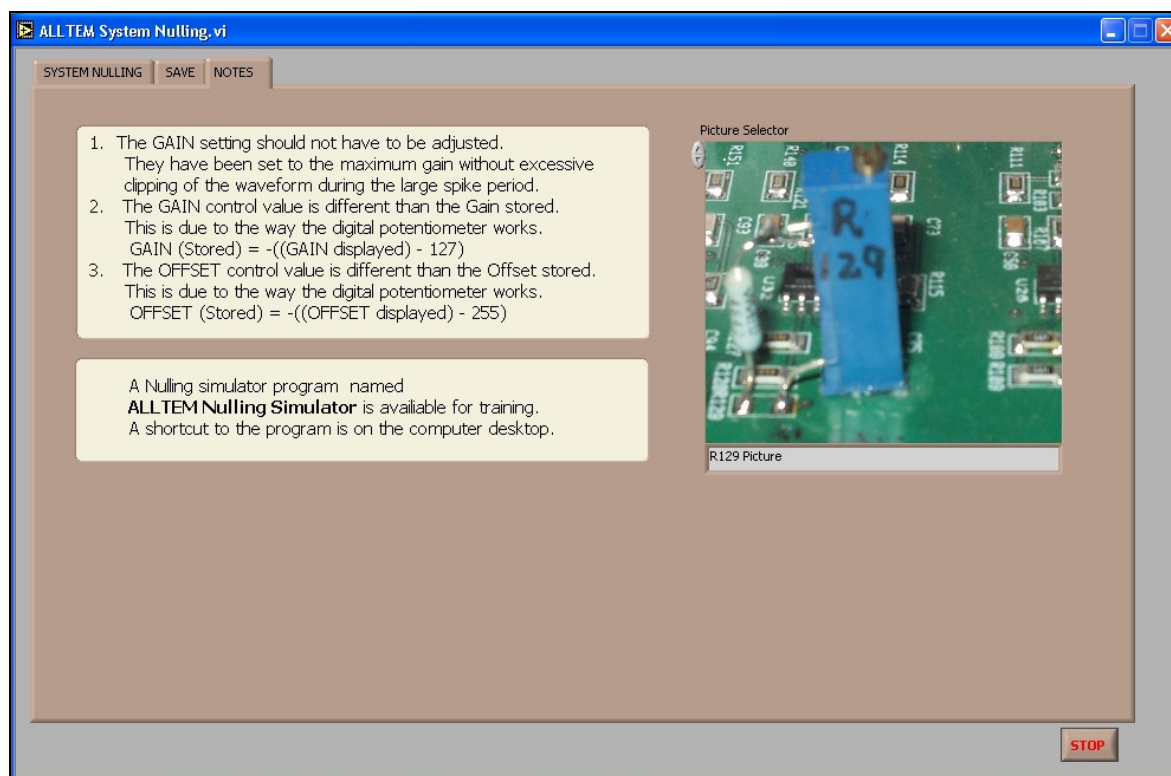
Figure 2.5. The **NOTES** tab with a photograph of potentiometer R129.
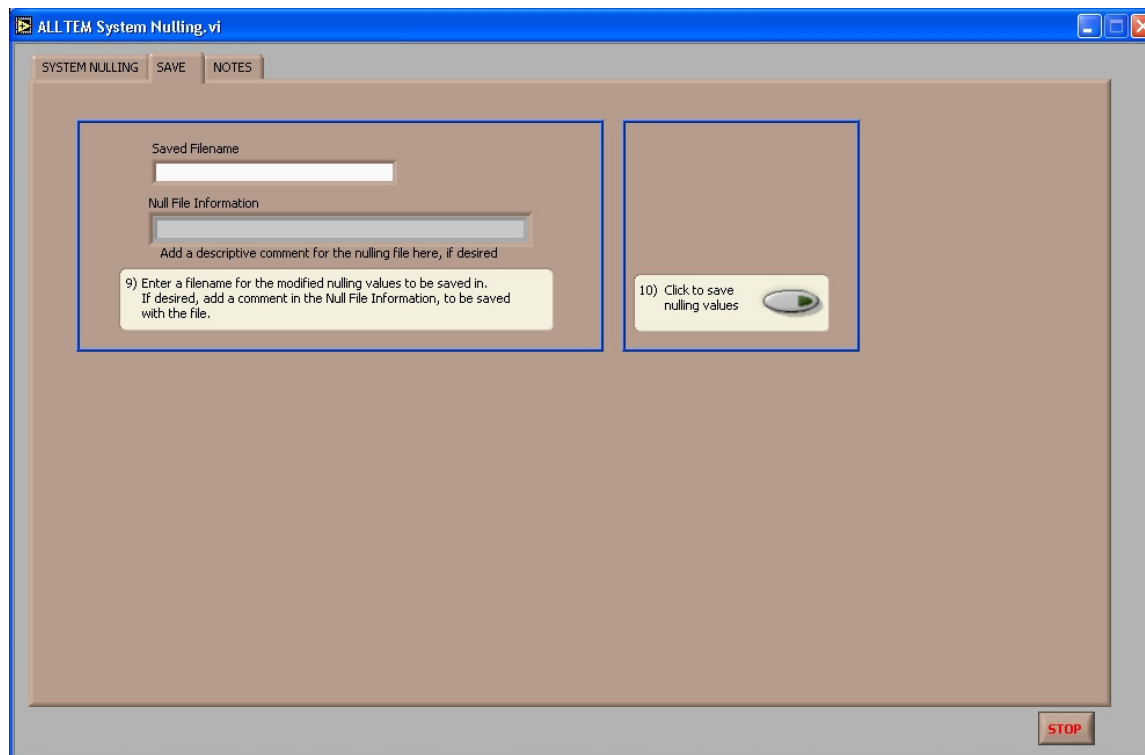
Figure 2.6. The **SAVE** tab with instructions.

3.0   DATA ACQUISITION SOFTWARE

3.1   Purpose

This software controls all functions of the ALLTEM system and handles digitizing and recording of all needed information. The software handles automatic sequencing of the three orthogonal TX coils and the various combinations of RX coil pairs. Analog voltages from each sequenced TX-RX coil combination are digitized. The digital data are recorded with the file names and headers that identify the information needed by the subsequent data preprocessing software. Header information includes position information from the global positioning system (GPS) and the Attitude Heading Reference System (AHRS) data that supplements the GPS data by adding roll, pitch, and heading information that can improve the accuracy of target classifications regardless of the type of target classification algorithms used.

3.2   Conditions for Use

This discussion assumes that the ALLTEM system is fully configured and operational with GPS and AHRS systems functioning. It also assumes that the ALLTEM RX coil pairs have been properly nulled as discussed in section 2.0.

3.3   Data Acquisition Operation

To start the program, double click on the icon "ALLTEM Data Acquistion_01.vi" shown in Figure 3.1.

Figure 3.1. The Data Acquisition Program icon.

Note: After the program has loaded the first time, the ALLTEM system touchpad may not respond correctly. If this happens, press CNTL-ALT-DEL on the keyboard and then click Cancel when the Windows Task Manager appears. This will allow the touchpad to work correctly in the program.

The opening screen will be a front panel like the one shown in Figure 3.2. To start this program click on the run arrow icon in the menu bar at the upper left (highlighted by the red arrow). This will bring up the setup screen shown in Figure 3.3.
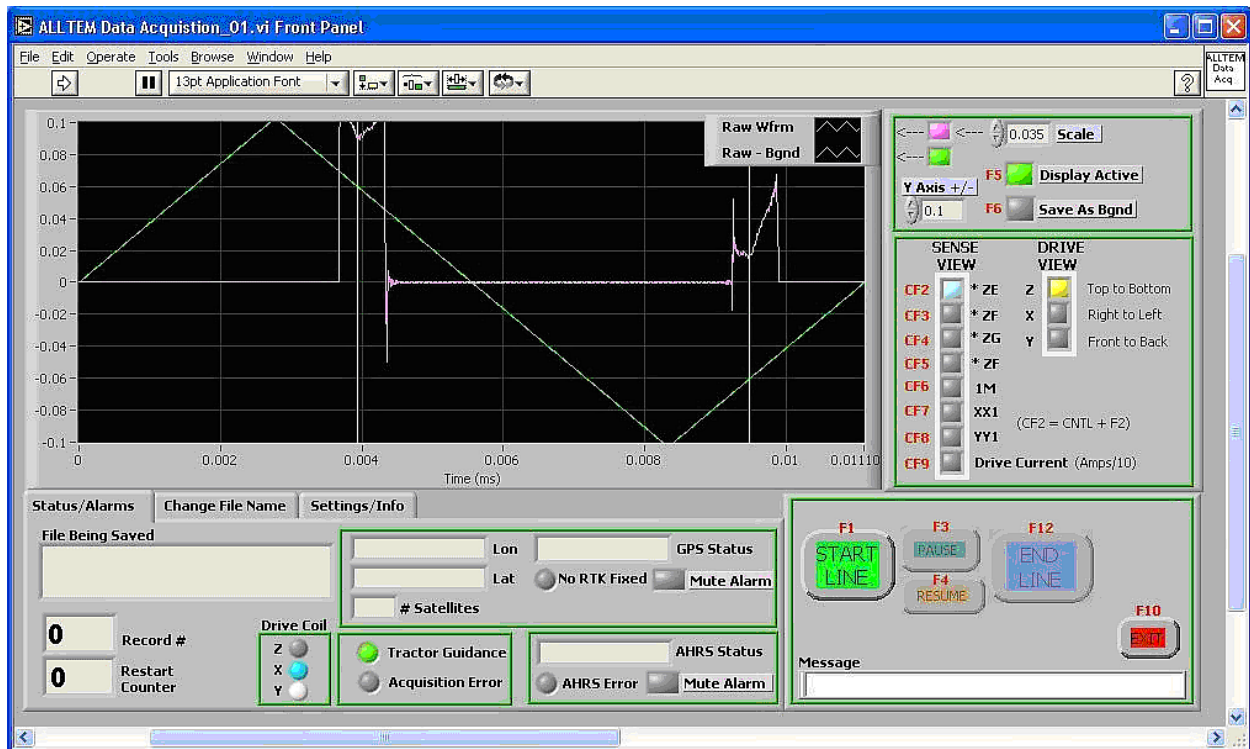
Figure 3.2. The Initial Front Panel. To start, click on the run arrow icon in the menu bar.

In the **SITE INFORMATION** frame are three fields into which information may be entered. The **Site** field allows entry of information about the site. This field has a limit of 42 characters, as indicated. The **Comments** field allows entry of any other information the operator might want to save. This field is also limited to 42 characters. The third, **Operator**, field allows entry of the operator's identification with a 7 character limit. The **Start Line** up/down button allows the operator to select a starting line number other than 0. This would be useful for cases where a large area had been only partially covered on a previous run and it is desired to resume data collection with the next line number. An integer number between 0 and 999 can be selected by the button or manually typed into the field.

Figure 3.3. The Setup Screen controls a number of configuration parameters, operating information and file names.

The **DATA FILE STORAGE** frame shows the directory into which the data file will be saved. The data file name can be changed by clicking in this field and typing a new or modified name (without file name extension). If it is desired to store the data files in a different directory, click on the folder browse icon to the right of **File Directory**. This will bring up the folder into which data files are currently being stored, Figure 3.4. You may select a different folder. The standard Windows operations also permit creation of a new folder.

To the right of the **File Name** field are two control boxes that may be checked or unchecked. During normal operations when data are to be stored, be sure to check the top box **Write to Disk**. The **Auto Line Inc** box, if checked, automatically creates a sequence of data file names corresponding to each line of stored data. For example, if data are being stored in files that begin with "example 1" the sequence would be "example1_0.xxx, example 1_1.xxx, example 1_2.xxx, and so on, where the "xxx" extensions refer to the identifiers for the various TX-RX coil combinations that are being recorded. It is suggested that this box be checked. If not, the data will all go into one file that could get very large over time. Putting all the data into one huge file risks losing the data if the file gets corrupted. It is suggested that a new directory be created for each survey area (such as CampStanleyB20 in Figure 3.4). Under that directory, create a new directory for each day of the survey (such as 23Feb11_CSB20), and select that directory with the Browse icon. Then, in the **File Name** field, name the base name of the files with the same name as the date directory (i.e. 23Feb11_CSB20).
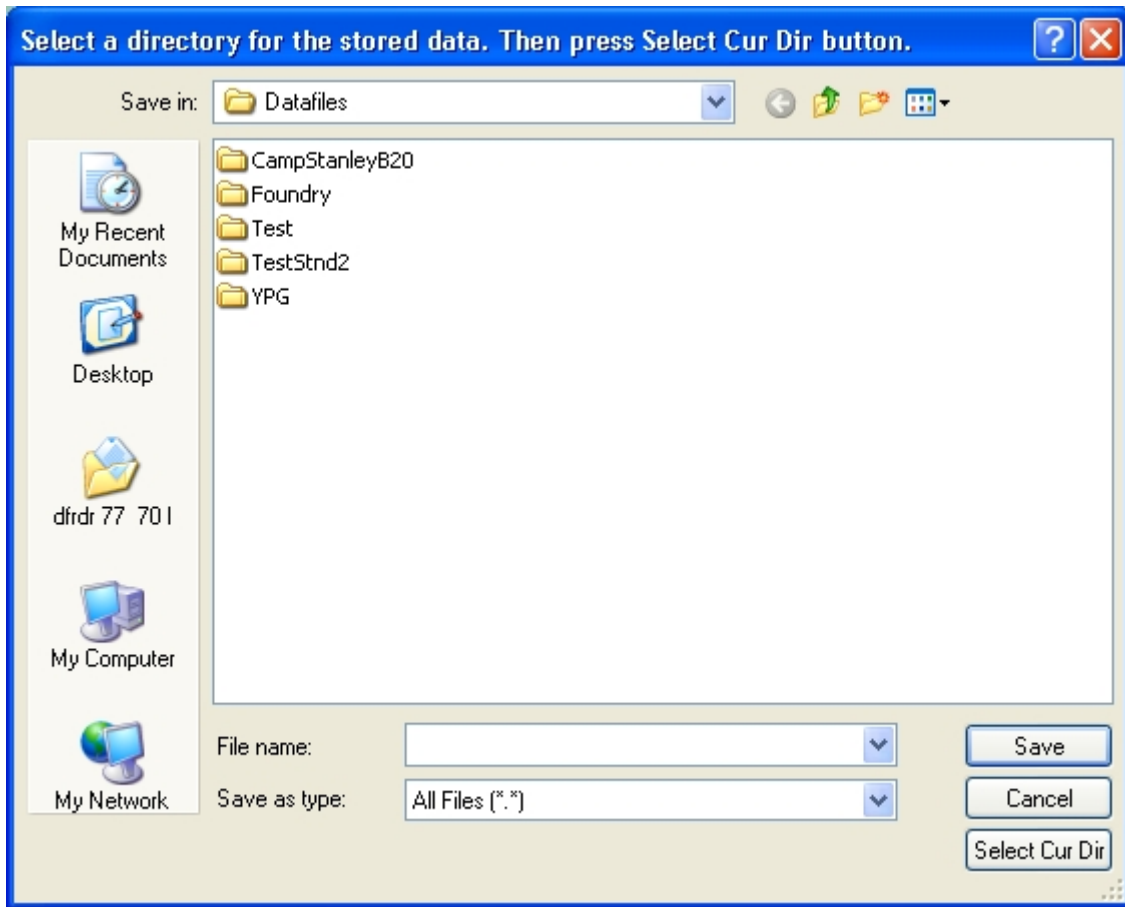
Figure 3.4. An example Datafiles directory. From this folder you can move to a subfolder and select it for use by clicking on the **Select Cur Dir** button at the lower right. The standard windows operations also allow creation of other folders.

The **SYSTEM NULLING FILE** frame shows the nulling file (see section 2.0 in this manual) that is being used and any comments that were entered into the header of that file. The adjacent browse icon will take the operator to the folder in which various nulling files have been stored. A different nulling file may be selected if desired. If a different nulling file is selected and the **ACCEPT** button is clicked, the newly selected nulling file will be used – not only for the current use of the program, but also for all subsequent uses of this program, until changed again by the operator.

The **GPS MODE** frame in this example shows "RTK_FX." See the GPS operation part of this manual for definitions of the various modes of operation. Note, however, that for reliable inversions of the data to get target physical parameters and classifications, accurate positional information (within +/- 5 cm or better) is required. The only GPS mode that can provide such accuracy is the Real-Time Kinematic Fixed (RTK-FX) data quality. Fixed here means that the GPS signal phase information is being used, that is, there is no cycle-slipping. For short drop-outs the system reverts to a predictive algorithm that may or may not be within the required accuracy. We will discuss GPS further in the discussion of the next screen.

The **AHRS** frame to the right of the **GPS MODE** frame contains a button. If this button is clicked, the AHRS unit data will be recorded in the data files. The purpose of this additional data stream is to add roll, pitch, and heading information to the GPS information. In cases where the site is very flat this may not be needed, but where there are topographic variations, the AHRS information should be used or the inversions for target parameters may not be accurate. We recommend that the AHRS data be used.

The **RUN CONFIGURATION FILE** frame always comes up with "LAST_RUN" as shown in Figure 3.3. The up/down button allows the operator to toggle through the saved configuration files. Select whichever one is desired. If changes are made to the current run configuration and it is intended to save these changes in a new configuration file, click the **SAVE** button and the configuration file directory will come up, Figure 3.5. Enter a new file name (in this case you must include the file name extension ".con") and click **OK**. If the **SAVE** button does not take you to the "Run Config Files" directory, use the Windows up arrow to navigate to the desired folder. Normally, these will be located in C:\ALLTEM System Settings\Run Config Files.
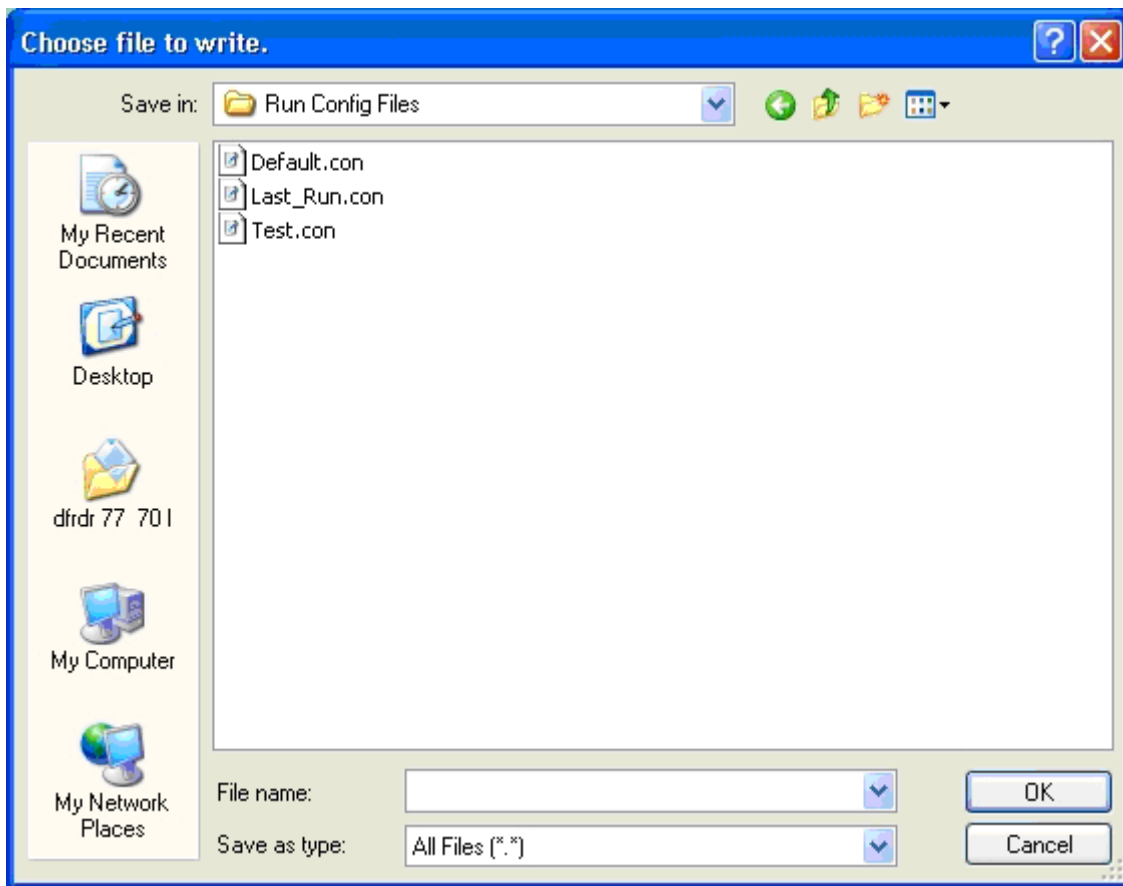
Figure 3.5. The "Run Config Files" folder. A new configuration file may be created by entering a new file name and clicking **OK**.

When the **ACCEPT** button is subsequently clicked, the new configuration file will be copied into "LAST_RUN."

The **COIL AMPS (PEAK)** frame can be used to adjust the peak current. Normally this is left at the maximum (11 A) value. The power amplifier should not overheat even in high ambient temperatures, but if it does, a lower peak current could be selected. Currently, there is no automatic overheating detection built into the software, but it can be detected by examining the normally sharp corners of the triangle Drive Current (bottom button in Sense View selector frame). One or both corners may become slightly flattened if overheating is causing the power amplifier to limit its maximum current. If overheating is detected, make sure the exhaust fan on the electronics chassis is operational. Also, if necessary, the chassis covers may need to be removed to increase air flow near the power amplifier. Another possible situation in which a lower current value might be chosen would be operation over very large, shallow targets where RX amplifier saturation might occur.

The **COIL DRIVE MODE** frame allows the operator to choose between the normal "Sequence" mode that automatically cycles through all three TX coil polarities, and a single-axis mode of operation. If the objective were high speed detection–and-location-only operation, a single coil, most likely the Z-axis coil, could be selected. If "Single" is selected, all three coil currents in the **COIL AMPS (PEAK)** frame will be set to the value of "0." The operator must then enter the current value, typically "11", that will be used in the selected axis. It is only possible to enter current values for the selected axis. The other two axes are set to "0" and are blocked from entering non-zero values. Note that if "Single" is selected followed by "Sequence," it will be necessary to manually enter "11" for each of the three axes. Previous current values are cancelled and erased when "Single" is selected, so unless the operator really intends to use only a single axis, it is recommended that the "Sequence" coil drive mode not be altered. Also note that if the coil drive mode is in "Single" when the **ACCEPT** button is clicked, that setting will be placed into the "Last-Run" configuration file and when the program is initiated the next time, the system will come up in "Single" mode.

The **Tractor Guidance** frame contains a button that is used to select whether the serial link to the tractor guidance laptop computer is enabled. If it is enabled, each time the END LINE button is selected on the data acquisition program, an end line signal, and the number of the next file to be saved is sent to the laptop computer over a serial link. If the serial connection between the two computers is not present, this should be disabled to prevent serial port error messages from appearing.

When all information and parameters are as desired, click the **ACCEPT** button at the upper right. A keyboard shortcut that avoids the use of the touchpad is to press the **F1** button.

When the **ACCEPT (F1)** button is clicked, the setup screen disappears and the system data acquisition panel is restored in fully operational mode. An example is shown in Figure 3.6.
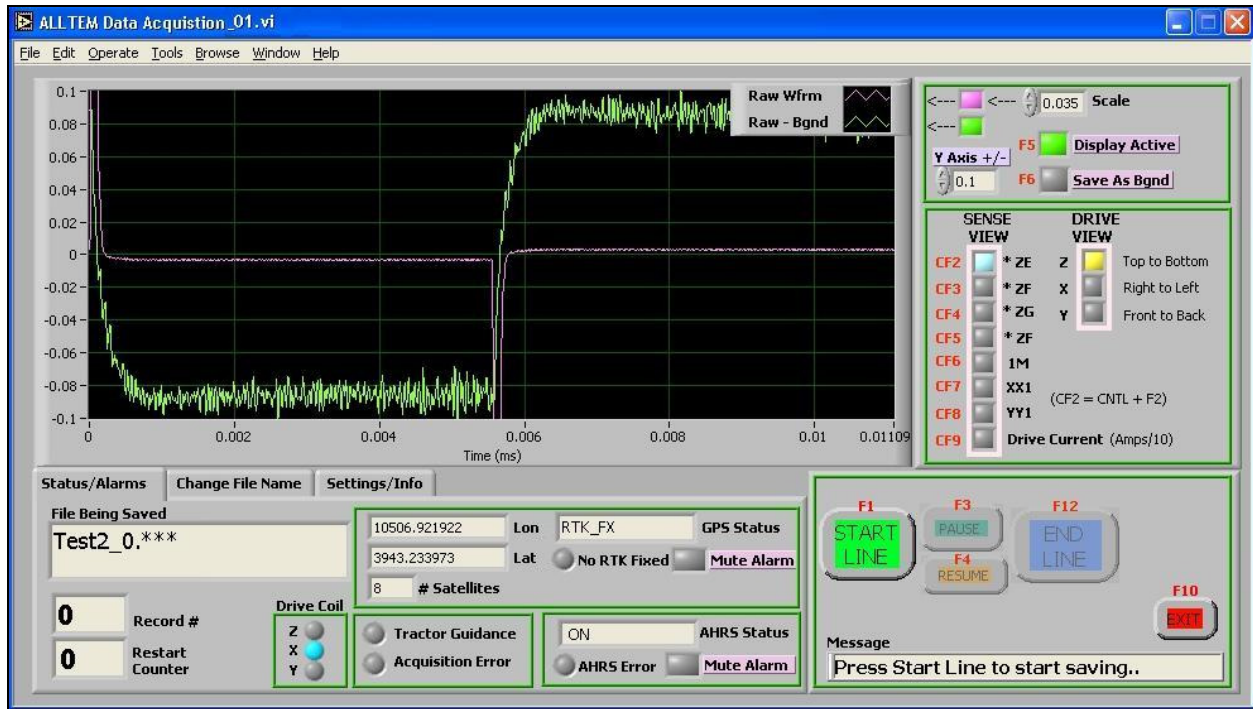
Figure 3.6. An example Data Acquisition Panel.

The example panel displays two waveforms. The pink trace is the raw data waveform, scaled by 0.035. The scale factor may be easily changed by the up/down **Scale** button to the right of the data display to keep it within the limits of the vertical axis, here shown as +/- 0.1 volt. In addition, the vertical, Y-axis range can be changed with the up/down **Y Axis +/-** button. The green trace is the raw data minus a background waveform, **Raw-Bgnd.** There are two additional buttons in this frame. The **Display Active** button shown in this example is illuminated, indicating that the display is active. This is the normal mode of operation and it can be very useful to see when the system has passed over a target. An experienced operator might also quickly recognize a data acquisition malfunction from this display. The display can be disabled by the operator if the data display is visually distracting. Another instance when the display might be manually disabled is when the **Restart Counter** under the **Status/Alarms** tab (discussed below) begins to count multiple times. This usually indicates that an operating system or user action has caused delays to the data acquisition loop. Shutting down the graphics data display makes extra time available in each data cycle, and therefore might alleviate the problem, though the tradeoff here is the lack of an immediate visual cue that something in the data acquisition is amiss. If the **Restart Counter** continues to count, it is highly advisable to occasionally toggle the **Display Active** button to check whether the data are unreasonable, indicating that something in the system needs attention. The **Display Active** button can be toggled using the **F5** function key, which is more efficient than moving a cursor with the touchpad and clicking.

The other button is **Save As Bgnd**. This button, when clicked, saves the current raw data waveform and subtracts that waveform from all subsequent waveforms. The button illuminates briefly while the background waveform is being stored. **This background subtraction operation only affects the waveform on the display. The saved data are *not* altered by**

background subtraction. During data collection it is recommended that this button be clicked at the beginning of data acquisition when the system is deemed to be not over a target. When this is done, the green trace is much more sensitive to deviations from the stored background waveform. Because of normal system drift, it helps to repeat this from time-to-time, when the system is not over a target. These repetitions reset the background to a more recently acquired waveform, thus compensating for system drift. The green trace – when the system is not over a target and the **Save As Bgnd** button has been recently clicked – would ideally be a flat line. There will always be some noise, of course, and some system drift as well. System drift produces a square wave, with spikes at the transitions, that grows in amplitude over time. This square wave drift can again be reduced in amplitude by a repeated use of the **Save As Bgnd** button. The **F6** function keystroke performs the **Save As Bgnd** and, as with the F5 function key, is preferred over using the touchpad.

In the example shown in Figure 3.6, the system is over a target, as is evident from the curved green waveform. The noise observed in the displayed waveform in this particular example is about +/-20 mV maximum. Noise can vary considerably depending both on local electromagnetic interference levels and what particular TX-RX coils are activated and observed and also based on what filter settings are used (see the ALLTEM system operator's manual). Substantial further noise reduction is accomplished in subsequent data processing.

In the **Sense View** and **Drive View** frame, just below the display control frame, the "1M" **Sense View** and "Z" **Drive View** buttons are illuminated, indicating that the data display is showing the data for the case that the vertical Z-axis (physically horizontal) TX coil is being driven and the data from the top and bottom 1-m RX coils are being displayed. The bottom button in the **Sense View** column will display the waveform current (Amps), divided by 10, for whichever drive coil is selected and can be used to check that the currents driving each TX coil in sequence are the expected triangle wave and are of the correct amplitude. Above this bottom button are 7 choices for RX coils and 3 for the TX coils. Nineteen of the possible 21 combinations are meaningful and recorded. The **XX1** sense is not meaningful when the drive coil is **Y** and the **YY1** sense is not meaningful when the **X** drive coil is selected. Waveforms will appear for these cases, if selected, but they will likely be saturated and, in any event, are not recorded. In order to select a particular RX coil pair in the **Sense View** column either move the cursor with the touchpad over the desired button and click, or use a combination of the Ctrl key + Function key (pressed simultaneously) as shown by the abbreviations in red on the pane. For example, CF3 denotes Ctrl+F3 key. The drive (TX) coil selection must be done using the touchpad.

In the example shown in Figure 3.6 the **Status/Alarms** tab is selected. Under this tab a number of pieces of information and alarm indicators are shown. In the **File Being Saved** field the filename "Test2_0.***" appears. The "_0" part of the file name indicates that this is the first line of data in a series of lines. This part of the file name will increment sequentially to "_1", "_2", and so on, each time the **END LINE** button, in the frame to the right of this tab, is activated because the **Auto Line Incr** box in the **DATA FILE STORAGE** frame in the setup screen (Figure 3.3) was checked. The "**.***" file name extension stands for each of the 19 recorded TX-RX combinations that are recorded, as shown in Figure 3.4 above. Under the file name frame are two additional fields, **Record #**, and **Restart Counter**. The number "0" in this example indicates that 0 records have been acquired and recorded on the given line. When **START LINE** is

clicked, the number will begin increasing. The number of records is the total records for the X, Y and Z polarity drives, so each polarity will have 1/3 of the value shown. The field will reset to "0" for each new line.

The **Restart Counter** ideally will remain at zero. A non-zero value indicates that the digital-to-analog (D/A) output that generates the signal fed to the TX coil current amplifier has lost synchronization with the analog-to-digital (A/D) board that samples the signals from the RX coils. **This condition causes anomalies in the data and might damage the switching relays as well,** because the electromechanical relays that switch between the three TX coils should only be switched when there is no current flowing in the energized TX coil. If the relays are switched open when significant current is flowing, high voltages will cause arcing at the relay contacts. If this happens repeatedly, then the contacts will be burned and pitted, causing their contact resistance to increase to an unacceptable level. The synchronization between the A/D and D/A boards is constantly monitored in software. Should synchronization be lost, the system is automatically stopped and restarted to recover synchronization. This happens without operator intervention, but it may take up to 1 second, so substantial gaps in the data along a line can occur. For these reasons, the Restart Counter should be watched, especially near the beginning and at the end of lines. Furthermore, restarts trigger an audio alarm, consisting of several beeps, designed to get the operator's attention. The **Restart Counter** audio alarm cannot be muted. There are several possible causes of this condition. It can occur just after the **START LINE** or **END LINE** buttons have been clicked, in which case the system is probably not yet moving or is outside the planned survey area, so there is no real consequence. Occasionally it happens when the GPS loses RTK-FX, or if serial communication with the GPS or AHRS unit is lost. It is also possible for the Windows OS to initiate a background service request that slows the cycle time. The operator is advised to use the shortcut function keys, rather than the touchpad, as much as possible in order to minimize system overhead. **Should the Restart Counter increment repeatedly, something is amiss and data collection should be suspended until the cause is determined and corrected.**

The **Drive Coil** display, to the right of the **Record #** and **Restart Counter** fields, flashes a button to show which of the three orthogonal, X, Y, or Z, drive coils is currently activated. This display is automatic.

To the right of the **File Being Saved** field is a frame devoted to GPS that contains four fields and two buttons. In the left column are longitude, **Long**; latitude, **Latit**; and number of satellites, **# Satellites.** The longitude and latitude numbers are the strings that came over the serial port from the GPS unit and indicate the location of the rover GPS antenna on the ALLTEM cart. When the cart is in motion these numbers should be progressively changing. The **# Satellites** field shows the number of satellites the GPS system is using to calculate positions. This is one factor in the precision of the calculated positions. See your GPS manual for more information regarding position error bounds. In the second column there is a field labeled **GPS Status.** In this example the field reads "RTK_FX" indicating real-time-kinematic fixed mode. Immediately under this field is a button that will illuminate when any condition other than "RTK_FX" exists. **Note that RTK_FX is the only GPS status that is expected to produce the accuracy necessary for target classification.** Modeling has shown that positions with errors no more than +/- 5 cm are needed for confident inversion/classification results (other data conditions are also relevant here,

but discussed elsewhere). When the GPS loses "RTK_FX", an audio alarm sounds and the button is illuminated. If the audio alarm is not desired, it can be muted by clicking the **Mute Alarm** button.

Under the GPS frame are two smaller frames. On the left is a frame with buttons labeled Tractor Guidance and Acquisition Error. The Acquisition button will illuminate if either there was a non-zero current at the time the drive coils were switching, or the data acquisition loop took more than 20 ms past the normal time that the A/D waveform buffers should have been read during the data acquisition loop. The Tractor Guidance button indicates whether the Tractor Guidance button was selected in the setup screen, Figure 3.3.

Moving to the right, the next frame is devoted to the AHRS subsystem. There is only one field, the **AHRS Status**. This field indicates, "ON". If the operator had not clicked the AHRS button in the setup screen, Figure 3.3, then "AHRS Not Used" would have appeared. We recommend that AHRS data be recorded. When AHRS data are being recorded, the two buttons will be active. The **AHRS Error** button illuminates if an AHRS data error were to occur, and an audio alarm would sound. The **Mute Alarm** button, when clicked, mutes the audio alarm.

The final frame on the lower right contains the main controls, consisting of five buttons and a message field. The buttons are, **START LINE** (F1), **PAUSE** (F3), **RESUME** (F4), **END LINE** (F12), and **EXIT** (F10). Although these buttons can be activated using the touchpad, it is more efficient to use the indicated function keys: F1, F3, F4, F12 and F10. Note that the grayed-out buttons are not available, because they do not make sense under the circumstances. For example, in the case of Figure 3.6, the system is not storing data on a line, so only **START LINE** makes sense. Once **START LINE** has been clicked, **PAUSE** can be selected if it is necessary to stop for some reason while on a line. **PAUSE** only suspends the saving of waveforms. When ready to proceed, the **RESUME** button can be clicked, and saving will restart. The buttons that are bold are available. The message field shows "Press Start Line to start saving.." The **START LINE** button cannot be activated in this screen unless the **Write to Disk** box in the **DATA FILE STORAGE** frame in the setup screen, Figure 3.3, was checked. Accordingly, it is good practice to read the message field just after the **START LINE** button has been clicked. **Note: there is no built-in protection against failure to click the START LINE button!** After **END LINE** has been clicked the **EXIT** button is available. This button should be used to exit the program because it allows the program to shut down gracefully and guarantees that the current to the drive coil has been set to zero. When the **EXIT** button is clicked the program exits and brings up the initial front panel (Figure 3.2). At this point the operator can either restart the program by clicking the run arrow icon on the menu bar, or close the program using the Windows "X" button.

When the **Change File Name** tab is selected (Figure 3.7), the operator is given the option of changing the file name into which data are being stored. The only normal use of this option is for taking calibration data, when it is desirable to keep the TX coils active without any interruptions while renaming data files to correspond to the calibration ball locations.
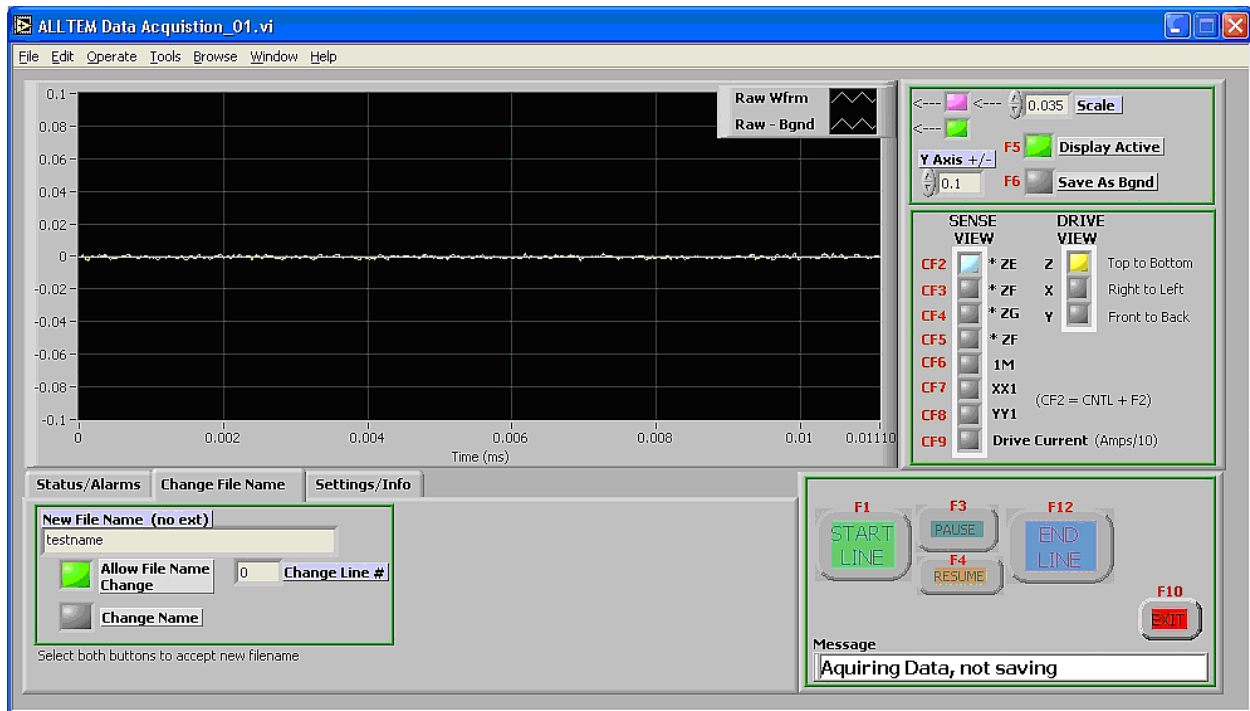
Figure 3.7. The **CHANGE FILE NAME** tab, lower left of screen, allows the operator to choose another file name for storing subsequent data.

To protect against accidental file name changes, two buttons must be clicked before an actual file name change is implemented. First click on the **Allow File Name Change** button, then enter the desired new file name (without extension). If a revised line number is desired, enter the number in the **Change Line #** field. Then click on the **Change Name** button to implement the file and line number changes. This action will cause both buttons to revert to their non-illuminated state, ready for another file name change, as desired. Below the box is a comment: "Select both buttons to accept new filename." The **Settings/Info** tab brings up a screen that includes a **Debug Mode** button, as shown in Figure 3.8.
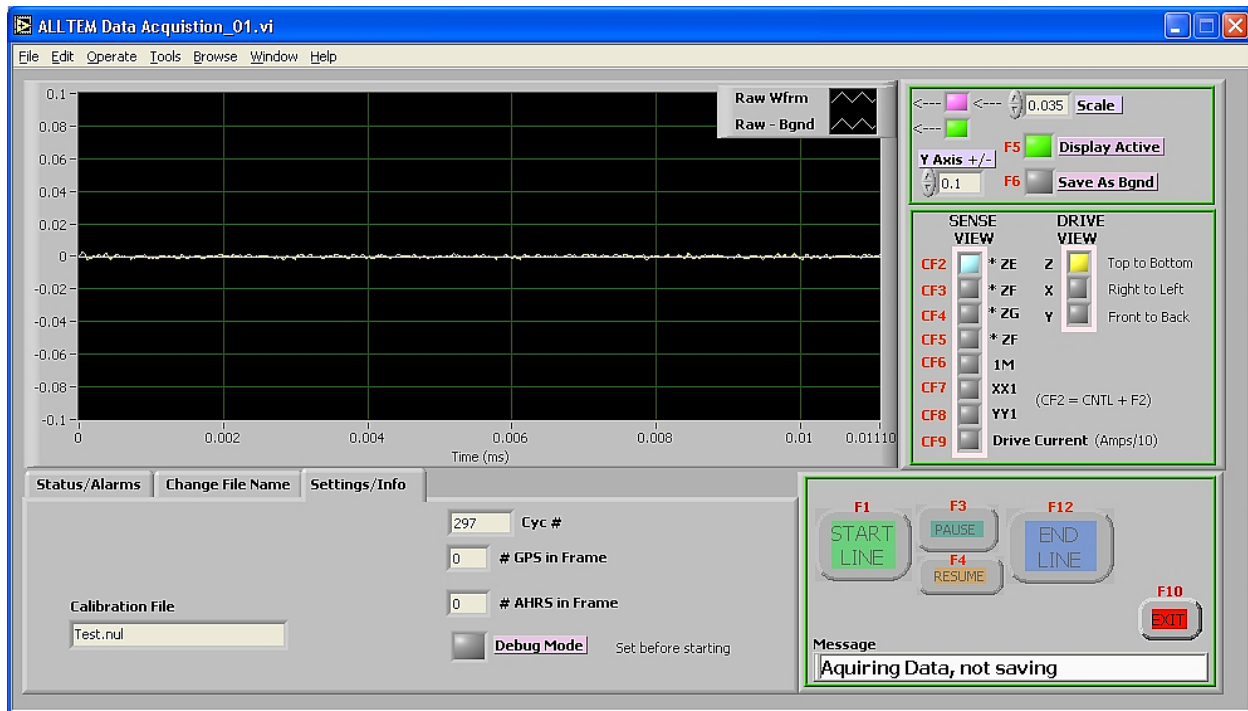
Figure 3.8. This **Settings/Info** tab screen brings up four fields and a **Debug Mode** button.

This screen includes the fields **Calibration File**, **Cycle #**, **# GPS in Frame**, and **# AHRS in Frame** and the **Debug Mode** button. The **Cycle #** field shows the number of data cycles of 90 Hz that have been completed since the program was started. This number will be reset to "0" and count up from there every time the program is restarted by the operator, as well as every time the program automatically resynchronizes (see discussion of the **Restart Counter** above). In Figure 3.8, the AHRS was not enabled and the GPS mode had been selected to NO_GPS, so both values are "0". When the GPS mode is other than NO_GPS, the **# GPS in Frame** field indicates how many GPS readings are included within one frame, where one frame is 66 ms long and corresponds to the amount of time required for data acquisition for one polarity of the TX (33ms deadband for relay switching + 33 ms of waveforms) . This value is usually "1", but may be "2" because the GPS updates position information every 50 ms and is asynchronous to the ALLTEM 66 ms data frames (update rate). When the AHRS is being used the **# AHRS in Frame** will usually be "2" because the AHRS updates data at an approximate 30 ms interval.

The **Debug Mode** may slow the system and normally is not used. If it is used, the **Debug Mode** button should be set before starting. It displays additional information to assist a system expert in diagnosing problems. This functionality is outside the scope of the present document, and will not be discussed further here. Contact a USGS ALLTEM system engineer if debugging is needed.

3.4   ALLTEM Tractor Guidance Program

This software program is located on the laptop computer mounted in front of the ALLTEM tractor engine. To start the program, double click on the icon called "ALLTEM Tractor Guidance_05.vi," shown in Figure 3.9.

Figure 3.9. Click this icon to start the ALLTEM Tractor Guidance program

The first screen is the main operating screen (Figure 3.10). In the lower left is a selection field named **Grid File**. Previously created grid files may be selected with the control. The one shown in the example is from a survey performed at Camp Stanley at a site named B20 with lines laid out parallel to the left side (PtL) of the survey area.
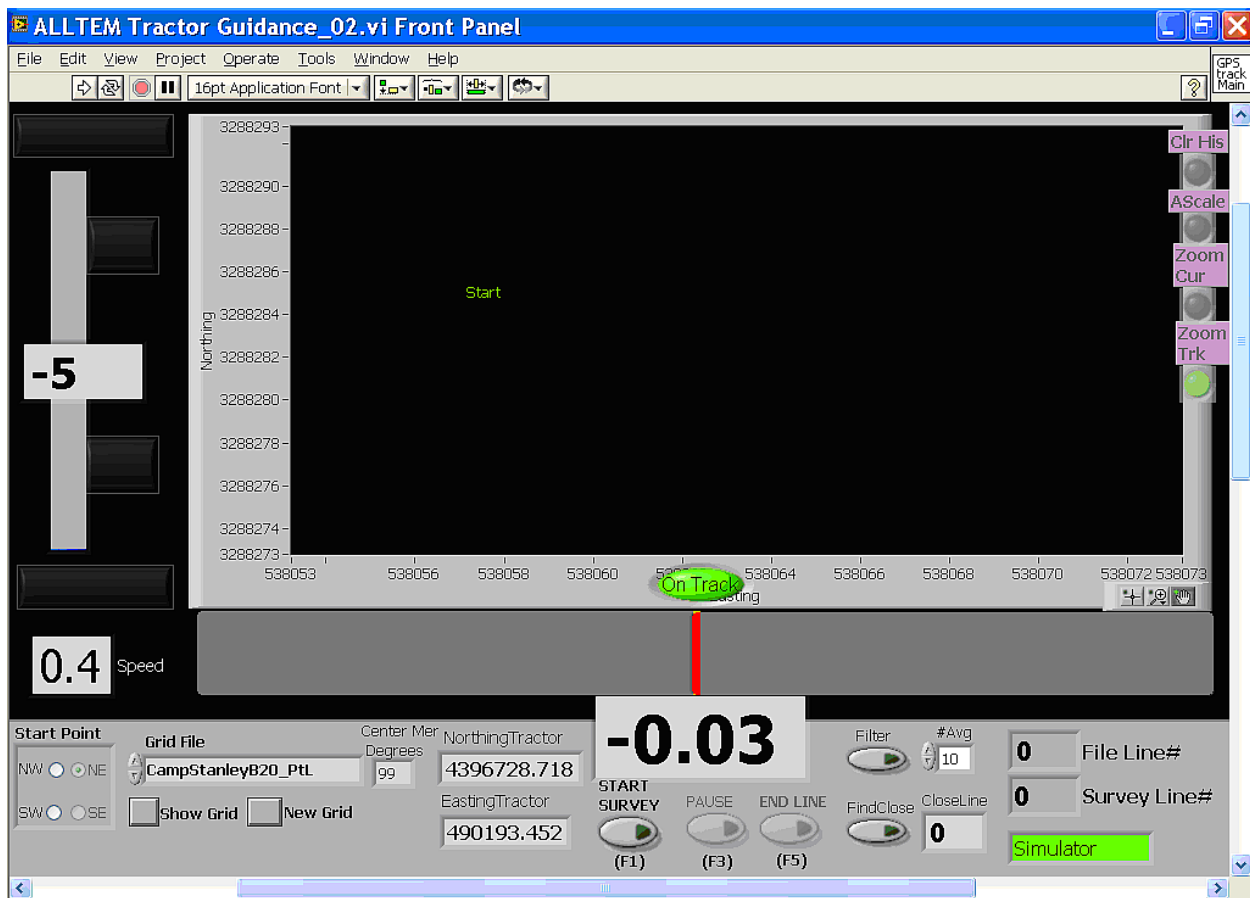
Figure 3.10. Main operating screen.

To view the survey lines which were planned for the selected Grid File, click **SHOW GRID.** The screen in Figure 3.11 will appear. The survey shown has hundreds of lines having many colors in the graph. When finished viewing**,** click **EXIT**.
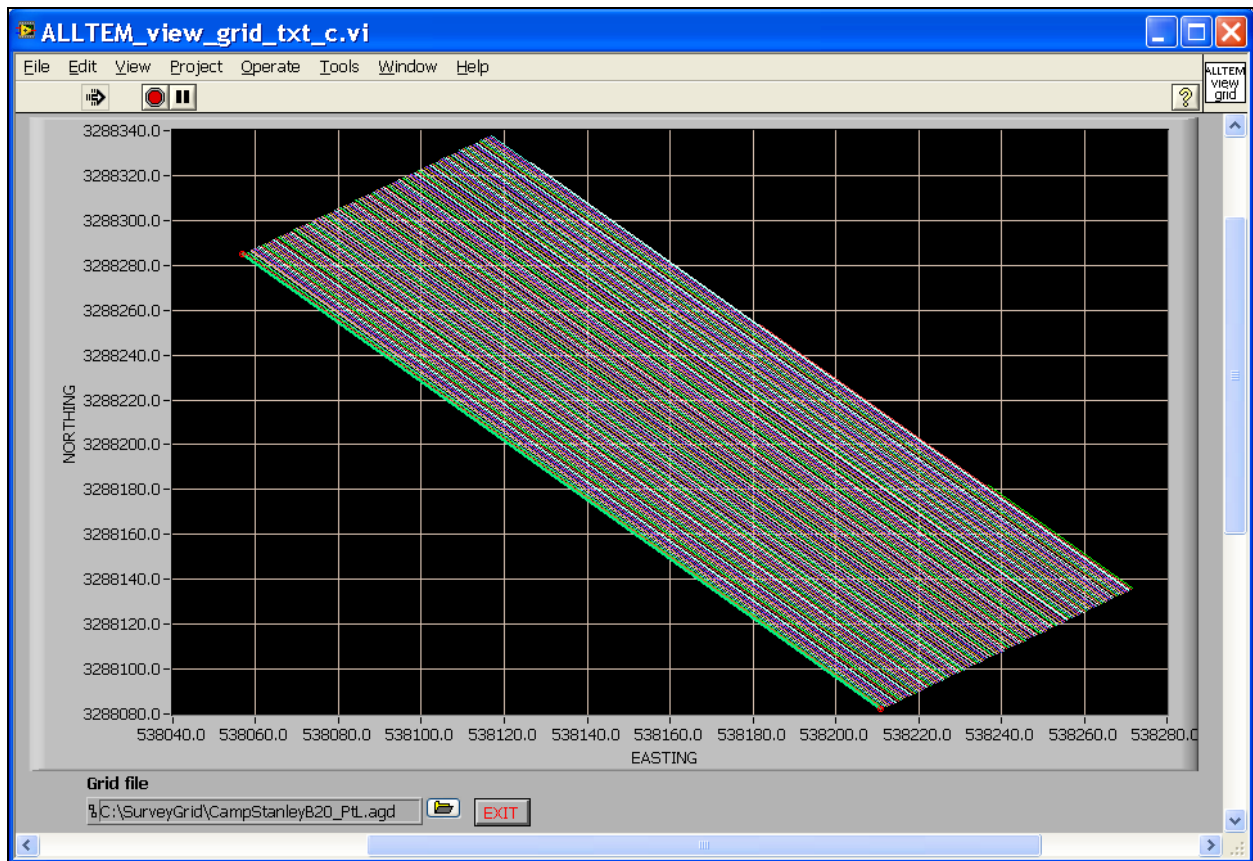
Figure 3.11. View Grid screen

3.4.1   NEW SURVEY GRID PLANNING

To plan a new survey grid, click **New Grid** on the main screen. The screen shown in Figure 3.12 will appear. To plan a new survey you must choose four points defining a quadrilateral shape over the area you wish to cover. The quadrilateral can be any four sided shape you want, (square, rectangular, trapezoidal, …etc. If the entire area that you want to survey can't be effectively covered with a single four sided area, you may have to break it up into smaller areas and perform surveys on each area separately. On the top of the screen is a selection frame that allows four ways to define the corner points. These are labeled: **//** **to a side**, **Four corners**, **From a file** and **From Get Here**. The **From a File** option is shown in this figure. Click the file browse icon next to **Grid File** to choose a previously created and stored .csv (comma separated variable) grid file. The program expects these files to be located in C:\SurveyGrid\CSV Files.
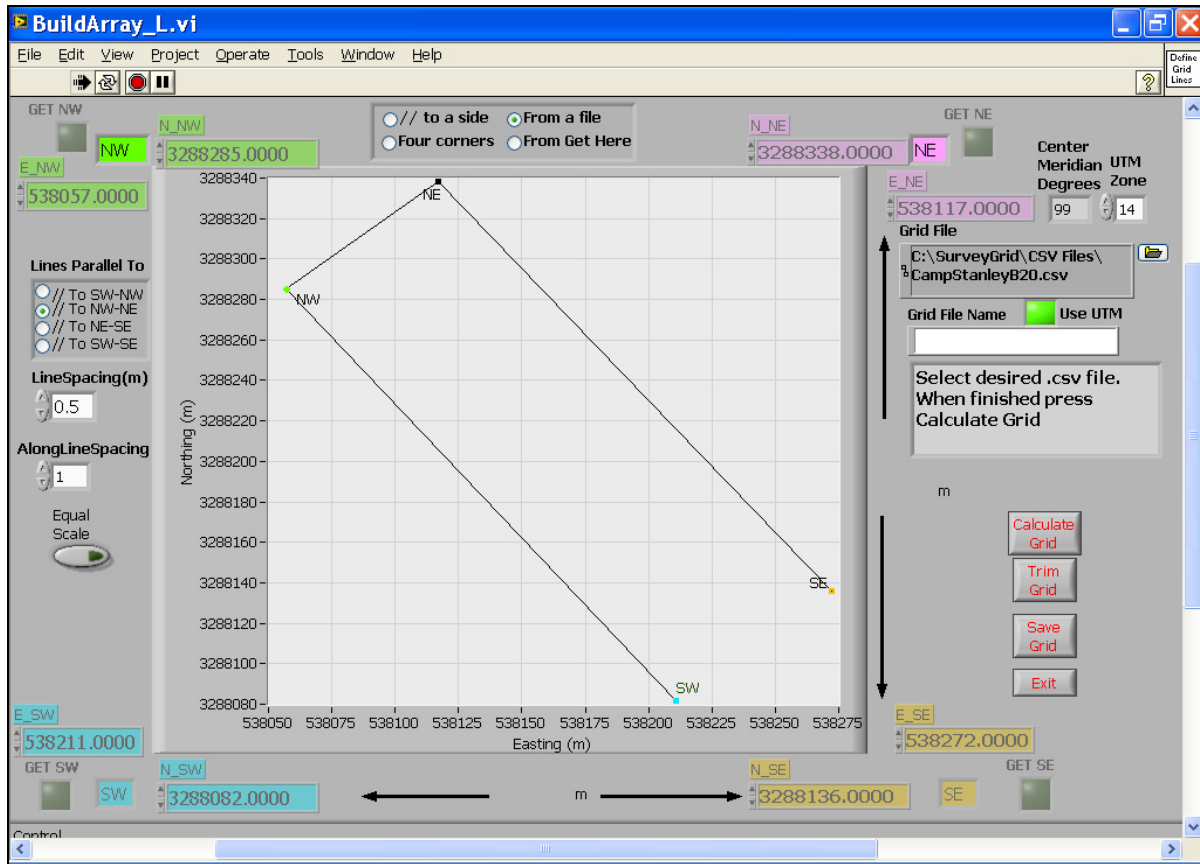
Figure 3.12. **Grid planning screen**, "From a File" option shown

3.4.2   CSV FILE FORMAT

The format of the .csv files is shown in figures 3.13 and 3.14. These were created in Excel and saved as a .txt file in the .csv format. One file format (Figure 3.14) is for the coordinates entered in just UTM coordinates, and the other (Figure 3.13) with latitude and longitude (in addition to calculated UTM coordinates and the latitude and longitude in other formats). If you use the latitude and longitude format, you need only fill in the values in the columns labeled DegMin.DecMin (degrees, minutes.decimal minutes). The program will calculate the UTM coordinates for you. The "UTM Zone" and "UTM Cmer" (UTM Zone Center Meridian Degrees) must be entered into the table.   The "UTM Cmer" and "DegMin.min" for the longitude column should be entered as positive numbers for the LabVIEW program which uses the data. This is noted as such in the table. The values in the columns to the right of "Easting" are the same GPS coordinates in other data formats. They don't have to be filled in and are not used by the program. If the .csv file you are using has just UTM coordinates, then select the **Use UTM** button (Figure 3.12). The four corners must be placed in the correct location (SW, NW, NE, SE). This can be checked by looking at the location of the labeled corners on the graph when the file is read in. If they are not correctly located, then the graph may look like that shown in Figure 3.15. If this occurs, stop the program (RED stop button on top of screen), exchange the corner coordinates in the .csv file and restart the program (arrow on top of screen), until the graph looks correct.

	DegMin.min	DegMin.min	Northing	Easting	Deg Min Sec.sec	Deg Min Sec.sec	Deg.deg	Deg.deg
UTM Zone	10							
UTM Cmer	123	Positive for Labview						
	DegMin.min	DegMin.min	Northing	Easting	Deg Min Sec.sec	Deg Min Sec.sec	Deg.deg	Deg.deg
SW	3636.255438	12146.9392	4051662.928	608905.672	36 36 15.32628	-121 46 56.35191	36.6042573	-121.78232
NW	3636.271912	12146.93979	4051693.375	608904.403	36 36 16.31474	-121 46 56.38744	36.60453187	-121.7823298
NE	3636.27239	12146.91936	4051694.644	608934.851	36 36 16.34338	-121 46 55.16146	36.60453983	-121.7819893
SE	3636.255916	12146.91876	4051664.196	608936.12	36 36 15.35493	-121 46 55.12594	36.60426526	-121.7819794
		enter as positive						
		for Labview prog						

Figure 3.13. **CSV file** with Latitude and Longitude coordinates

	DegMin.min	DegMin.min	Northing	Easting	Deg Min Sec.sec	Deg Min Sec.sec	Deg.deg	Deg.deg
UTM Zone	10							
UTM Cmer	123	Positive for Labview						
	DegMin.min	DegMin.min	Northing	Easting	Deg Min Sec.sec	Deg Min Sec.sec	Deg.deg	Deg.deg
SW	3636.255438	12146.9392	4051662.928	608905.672	36 36 15.32628	-121 46 56.35191	36.6042573	-121.78232
NW	3636.271912	12146.93979	4051693.375	608904.403	36 36 16.31474	-121 46 56.38744	36.60453187	-121.7823298
NE	3636.27239	12146.91936	4051694.644	608934.851	36 36 16.34338	-121 46 55.16146	36.60453983	-121.7819893
SE	3636.255916	12146.91876	4051664.196	608936.12	36 36 15.35493	-121 46 55.12594	36.60426526	-121.7819794
		enter as positive						
		for Labview prog						

Figure 3.14. **CSV file** with UTM coordinates, only
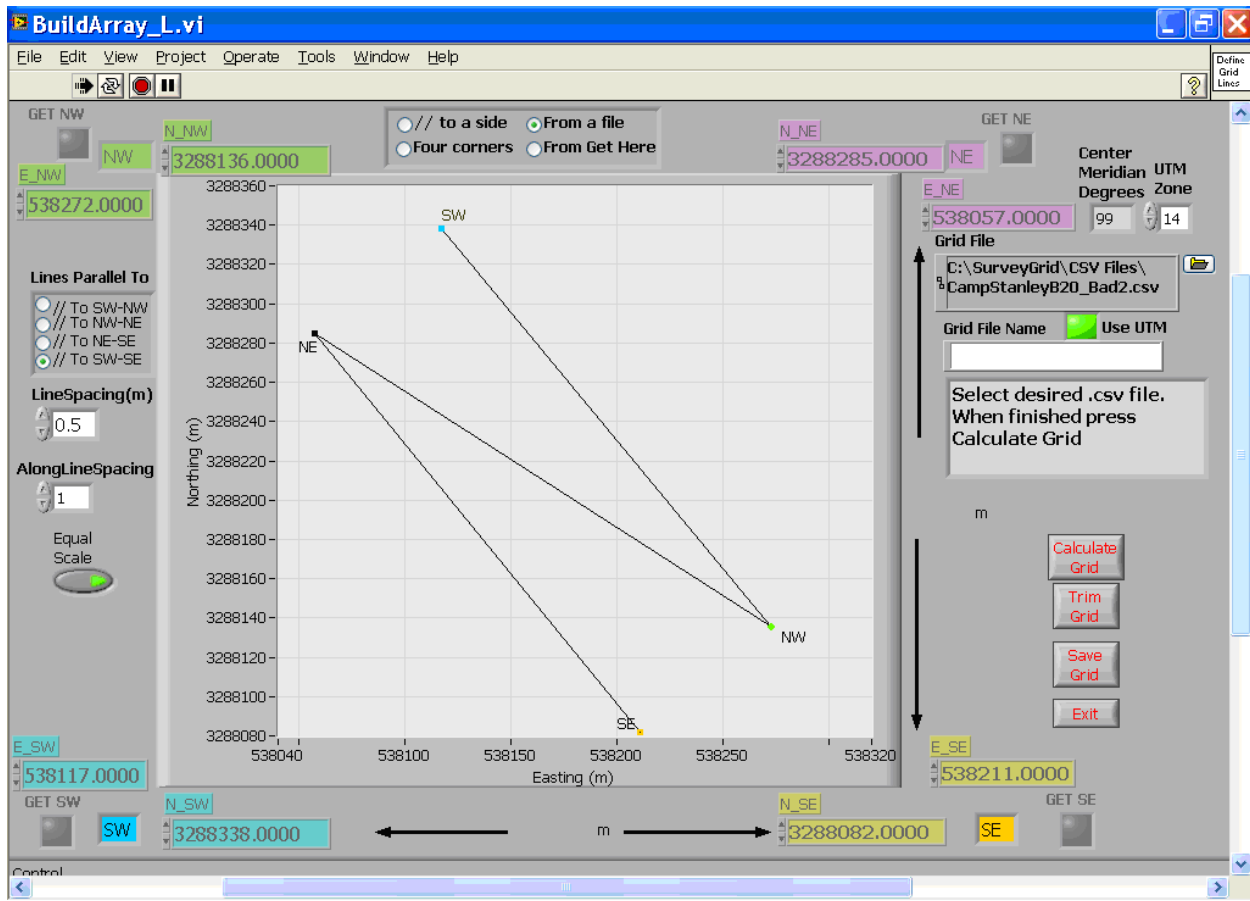
Figure 3.15. **Grid planning screen**, coordinates not placed in the correct location.

In the selection frame on the left labeled **Lines Parallel To**, select the side that you wish the survey lines to be parallel to. The sides are defined by their compass positions (SW, NW, NW, SE). If you don't want the graph to be auto scaled on the X and Y axis, then click **Equal Scale**. The **Line Spacing (m)** value may be adjusted, if needed. ALLTEM surveys are normally done with a 0.5 m line spacing, so this value should be left as is. The **Along Line Spacing** value is used by the program to define how many points along the line will be used when computing the survey area. Normally, this should be left at 1 m. Making it smaller will reduce the small "stair step" nature of the line endpoints when the survey lines don't end on a straight N-S or E-W line. However, smaller numbers will increase the computation time when the **Calculate Grid** button is subsequently executed. Next, click **Calculate Grid**. This will begin the process of filling the quadrilateral with an array of points defined by the **Line Spacing** and **Along Line Spacing** values chosen. This process could take minutes, depending on the size of the survey area. The **Line Progress** indicator shows how the computation is progressing (Figure 3.16). Once the array building is complete, the array of points will be plotted on the graph (Figure 3.17). This array contains more than 40,000 points, so the plotted points look like a solid block. As can be seen in Figure 3.17, the array area is slightly bigger than the four corners. This is to allow for possible adjustments for complete coverage, for irregularly shaped areas. In this case, the four corners are completely covered by the red area, so no adjustment is necessary. If adjustment were necessary, use the **Grid Adjust** control to move the array area to cover all four corners. Figure 3.18 shows

the effect of the adjustment. Once any necessary adjustment is finished, click **Trim Grid**. This will begin the calculation to remove all array points outside of the four corner area, and then to remove all array points inside the area, except for those on the start and end lines of the survey area. After this is complete, the graph should look like that in Figure 3.19.
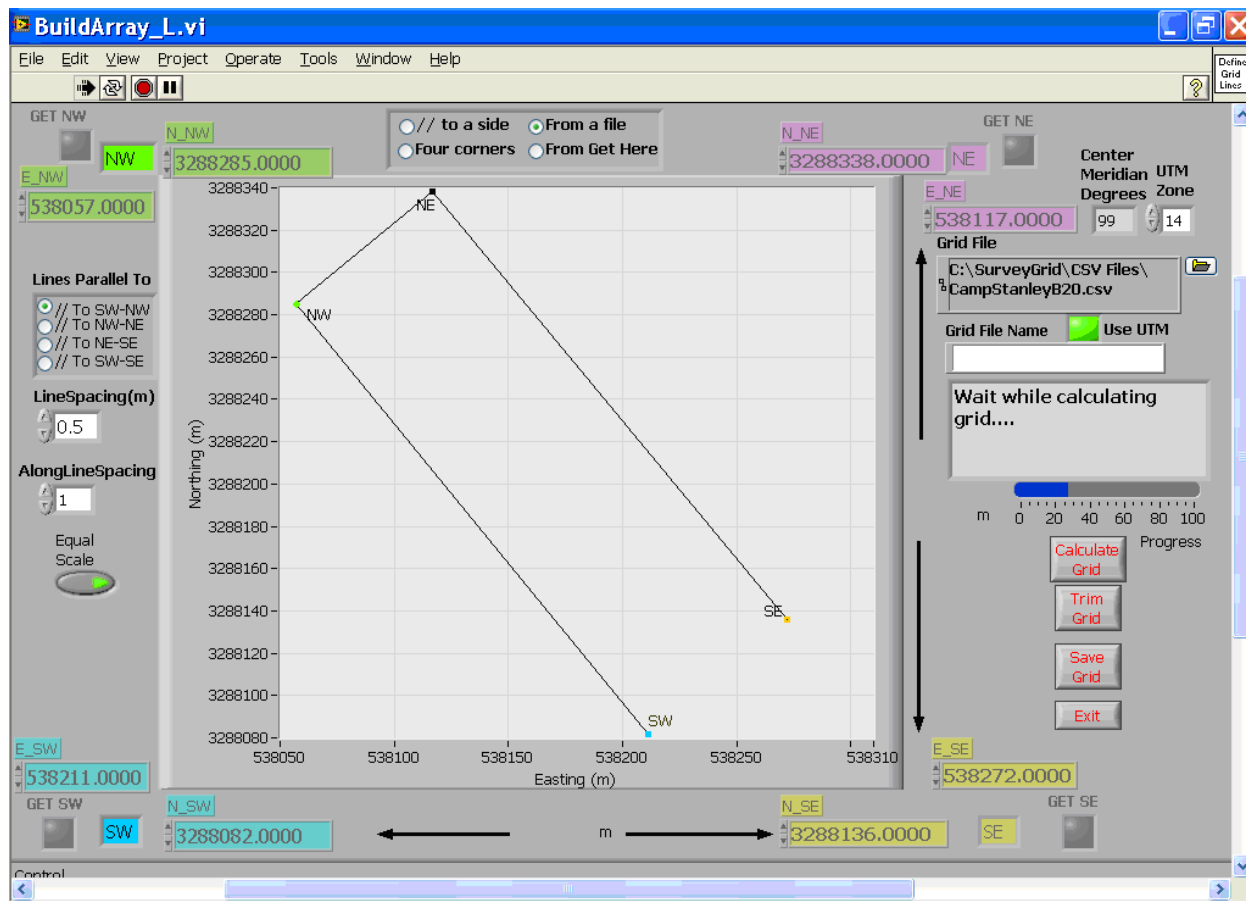
Figure 3.16. **Grid planning screen**, grid calculation in progress.
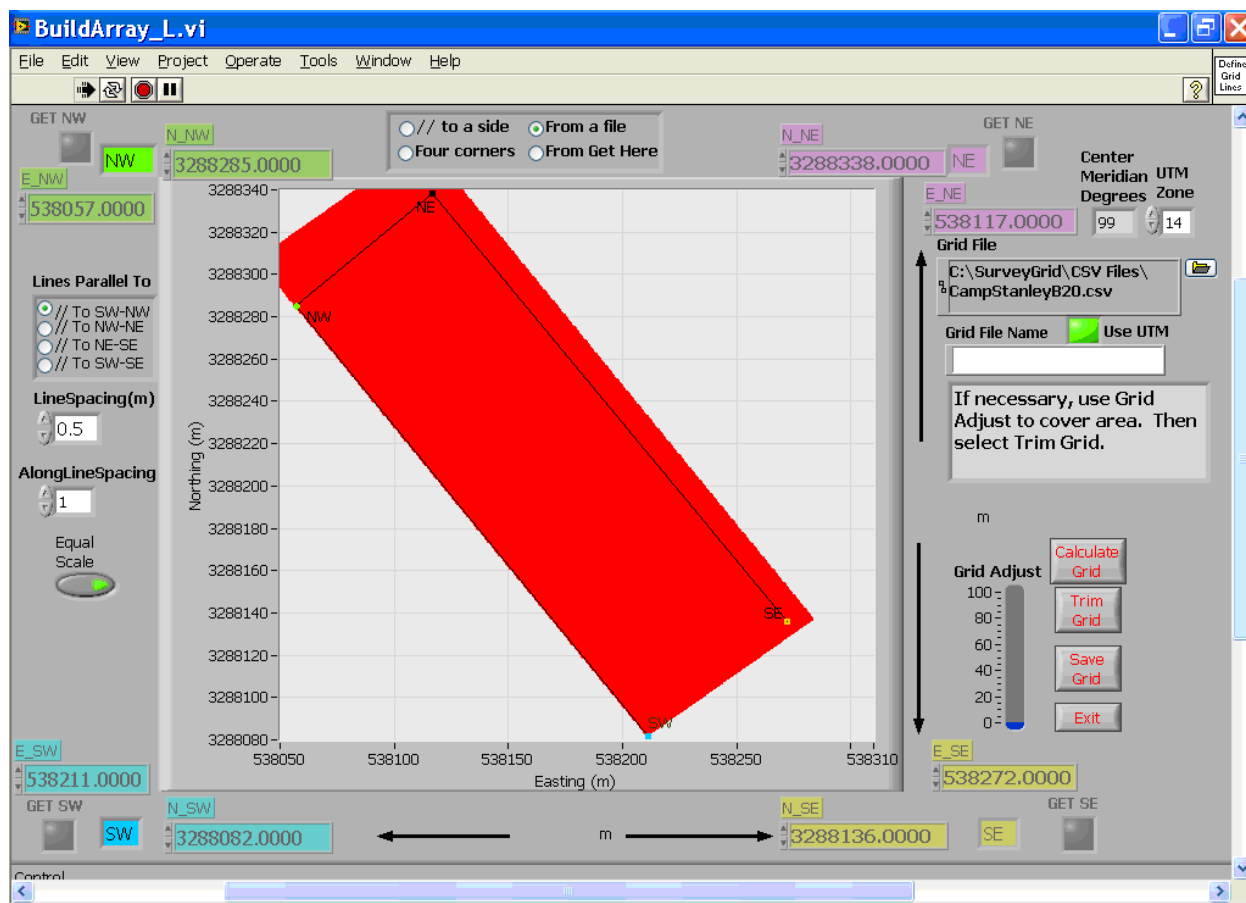
Figure 3.17. Grid planning screen, grid calculation done. Red array points are too close to show up independently.
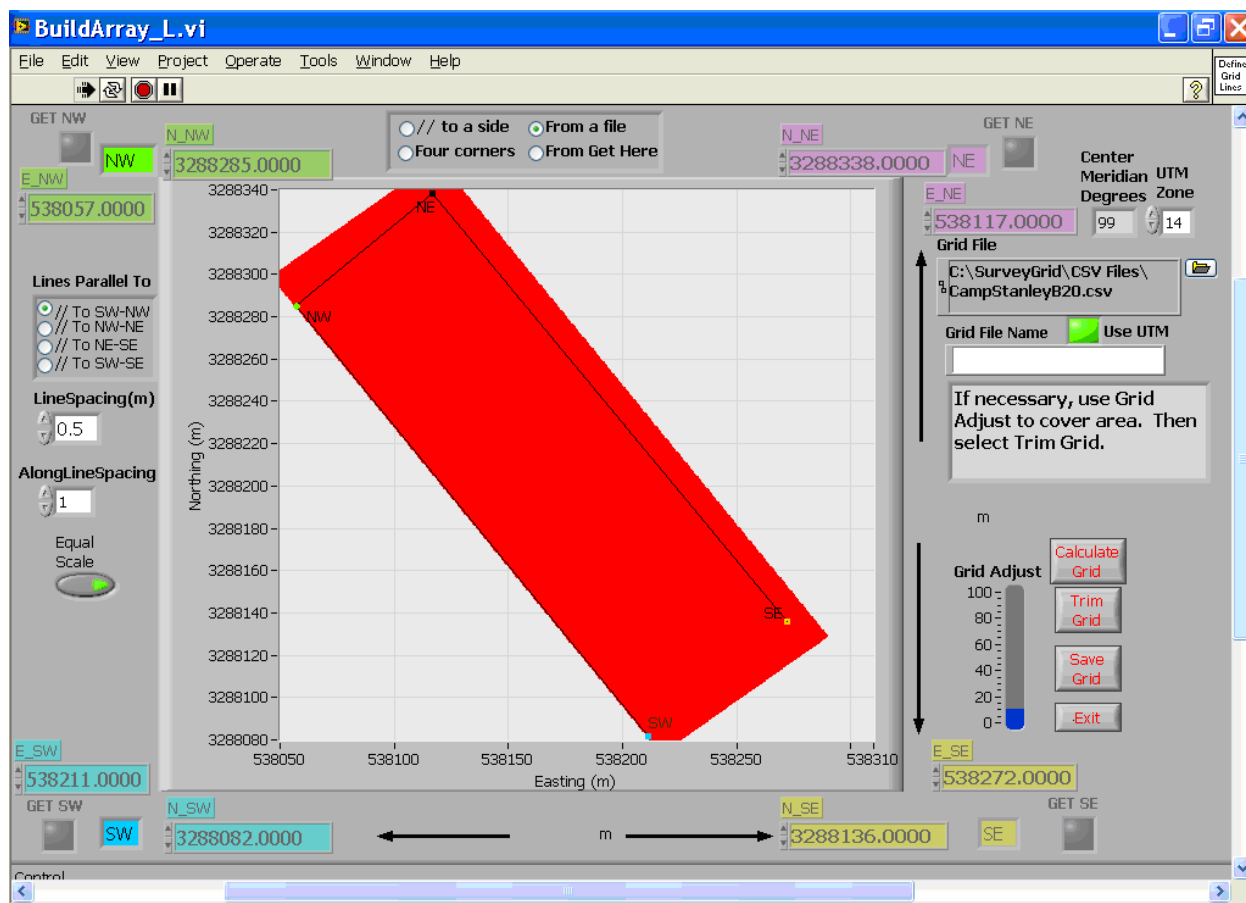
Figure 3.18. Grid planning screen, effects of using the Grid Adjust control.
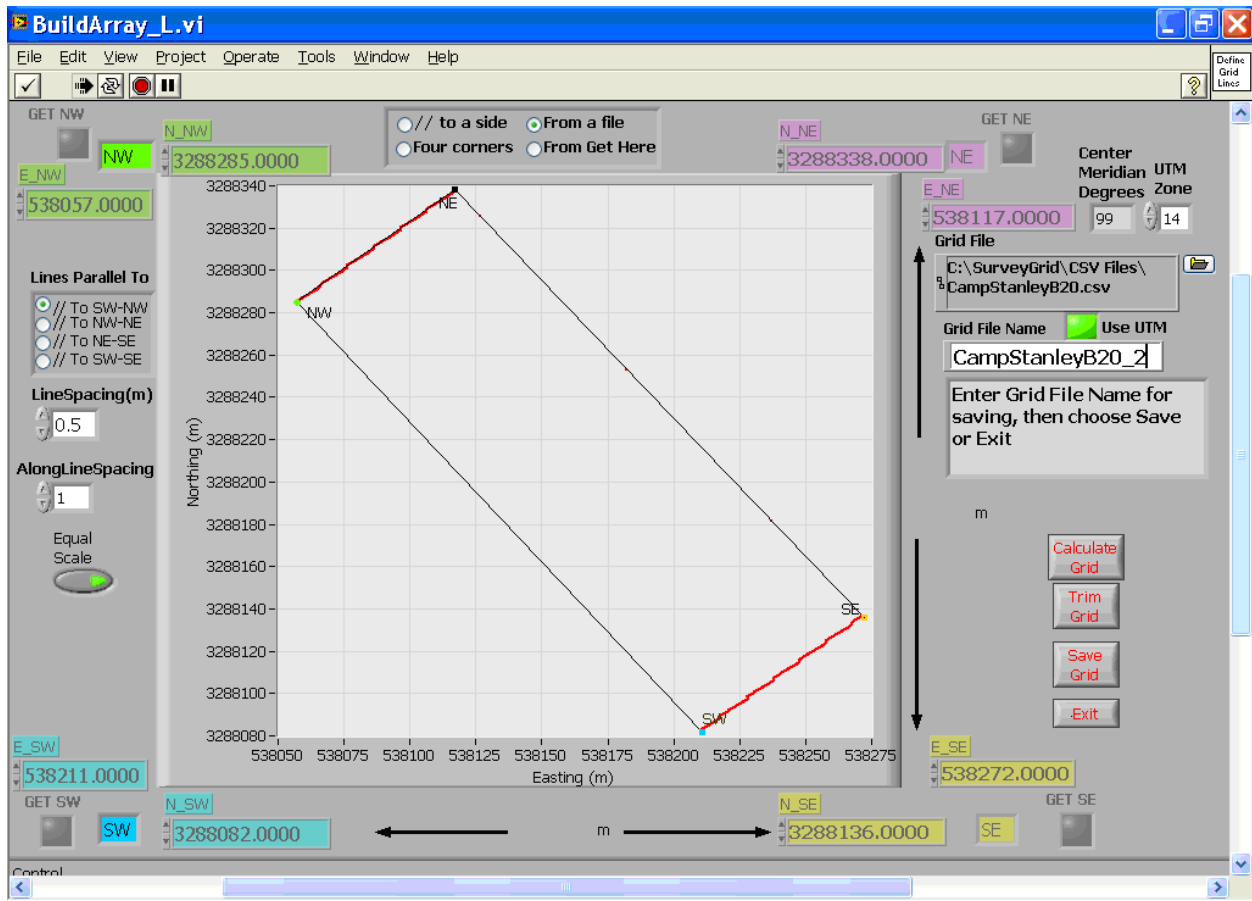
Figure 3.19. Grid planning screen, after the Trim Grid operation. A new Grid File Name has been entered, and is ready for the Save Grid operation.

After the Trim Grid operation is complete, the calculated grid endpoints can be saved to a file. In the figure, the new file name "CampStanleyB20_2" has been entered. Once the name is entered, click **Save Grid**. The created file will be saved in the C:\SurveyGrid directory with an .agd extension. (agd = ALLTEM grid). Once the file is saved, click **Exit**. This will return you to the main operating screen.

There are other options for entering the grid corners. The **// to a side** (parallel to a side) is used when you want to only choose a given side and then make a number of lines parallel to that line. To use this, enter the UTM coordinates of the end points of the line side chosen (**E_SW, N_SW, E_NW, N_NW** in Figure 3.20). The **Lines Parallel To** selector may be changed at any time to view the survey with different sides being the defining side. To control the number of lines in the survey, adjust either the **Width** (Figure 3.20) or the **Length** (Figure 3.21) control fields on the appropriate side of the quadrilateral.
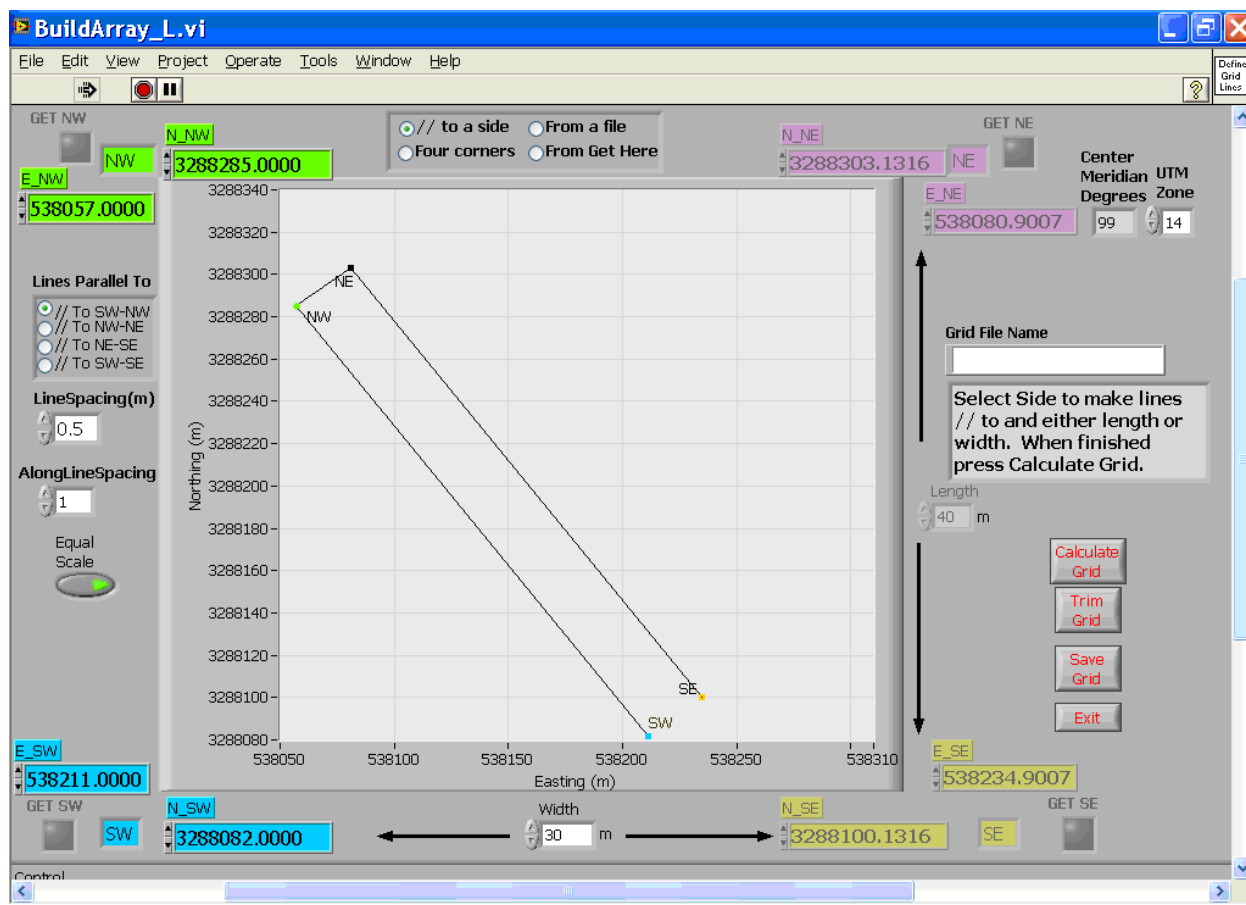
Figure 3.20. Grid planning screen, with option: // to a side, and // To SW-NW, Width = 30 m.
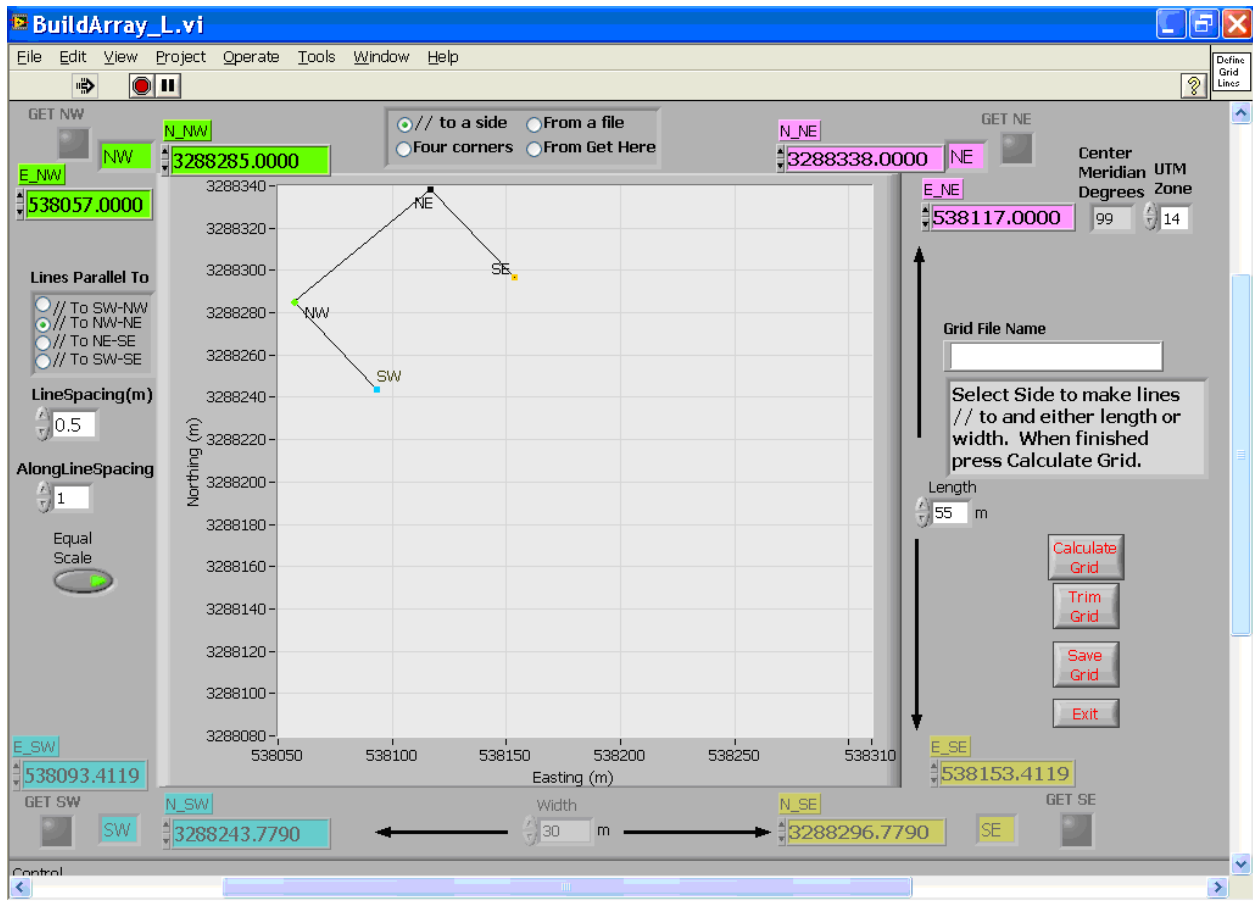
Figure 3.21. Grid planning screen, with option: // to a side, and // To NW-SW, Length = 55 m.

The **Four Corners** option allows all four corners to be entered independently. An example is shown in Figure 3.22. Here the **N_SE** and **E_SE** values have been changed to change the shape of the area.
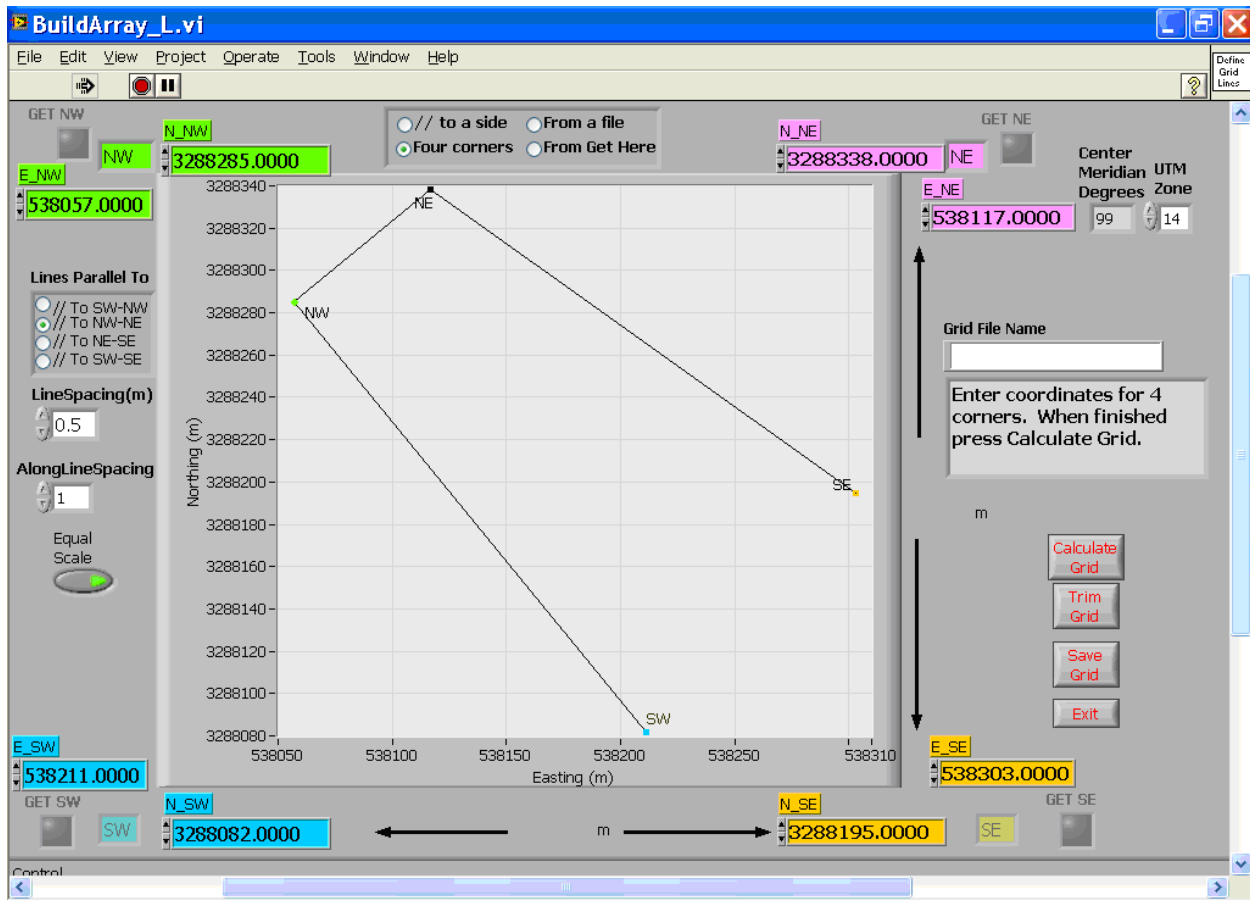
Figure 3.22. Grid planning screen, option: Four corners combined with // To NW-SW.

The **From Get Here** option can be used when the Leica GPS system used for the tractor guidance is operational, and is sending GPS positions to the guidance laptop computer on its serial port. This would be used if you wanted to drive the system to each of the four corners of a new grid, and capture the coordinates by clicking the appropriate **GET SW, GET NW, GET NE** and **GET SE** buttons, (see Figure 3.23). In the figure, note the **GPS Available?** button has been selected. With this button on, the current northing and easting values being read in from the Leica GPS will be displayed in the **Northing** and **Easting** indicators. In Figure 3.23, the **GET NW** button has just been clicked. At each corner, the appropriate **GET** button may have to be clicked a few times to have the current northing and easting entered into the associated N and E corner values. Visually check that the values update correctly when the associated **GET** button is clicked.
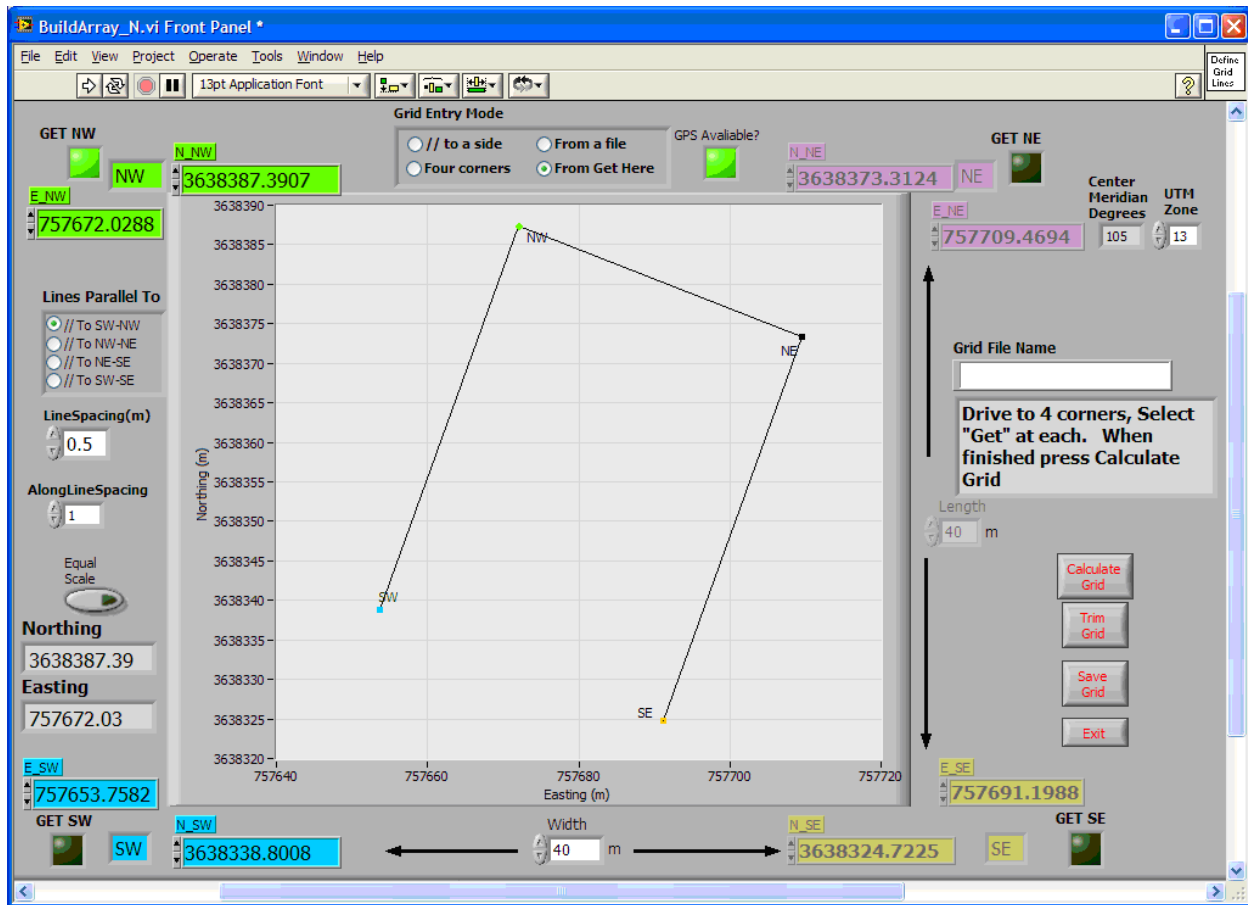
Figure 3.23. **Grid planning screen,** From Get Here option.

For any of the grid entry options described, after the corners are adjusted, the same procedures of **Calculate Grid**, **Trim Grid**, and **Save Grid** should be followed, as described in the **From a File** mode.

3.4.3   SIMULATOR MODE

For the following screens, the program was being operated in the Simulator mode (green indicator in the bottom right in Figure 3.24.) The Simulator mode allows operation of the basic functions, without the actual GPS unit being connected to the computer. The Simulator mode use is not described in this document. In the non-simulator mode, the Simulator message would be substituted with the quality of the GPS signal being received (i.e. RTK_FX, SPS, DIFFER, …), or any GPS error messages (i.e SERIAL TIMEOUT when no GPS is sensed at the serial port). If the GPS quality momentarily drops out of RTK_FX state, the operator should continue driving as straight as possible, until RTK_FX state is regained.

3.4.4   GUIDANCE PROGRAM OPERATION

Once the **Grid File** has been selected, the **Start Point** of the first line must be selected. As can be seen in Figure 3.24, the **Start Point** is **NW**. If instead, you wanted to start in the southwest corner, then click the **SW** button. Note, the word "Start" in green text color appears on the graph near the start of the current line. At the other end of the line, the word "End" appears in red text color. These aids are intended to help the driver identify the start and ends of the line. Due to an unsolved programming error, there are cases when the text may appear on the wrong ends of the line. The driver should be aware of this condition and mentally keep track of where they are on the survey grid, as a backup. After this selection, click **START SURVEY**. Note that the "(F1)" in Figure 3.24 indicates that the F1 key on the computer could also be used to start the survey.

The "(F3)" and "(F5)" keys perform similar actions for their associated buttons. In Figure 3.24 the first line of the survey is shown in green. The white line is the history of the path of the ALLTEM tractor. As can be seen the tractor is before the start of the first line. This is indicated by the status indicator, **PRE-START**. The "-2" on the left side indicates how many meters before the start of the line, that the tractor is currently located. The **On Track** indicator below the graph indicates that the tractor is within +/- 0.1 m of the desired line. In this case, it is indicating that the tractor is on track if the current line was projected back to the tractor's current location. In Figure 3.25, the tractor has traveled "5" meters past the start of the line and is "0.35" meters to the right of the desired line, as viewed by the driver. The colored bar above the "0.35" is red when the tractor is to the right of the desired line and yellow when it is to the left. To correct the "0.35" meter error, the driver should turn to the left and try to maintain the line error as close to zero as possible.

The history of the tractor's locations can be cleared by clicking the **CLR HIS** button. Additionally, the history is automatically cleared on a periodic basis, to keep the graph from becoming too cluttered. The length of the current line is shown as "245.5" meters in the indicator on the upper left. The "0.2" is the current speed of the tractor in meters/second. A normal survey speed is 1.0 meter/second. This speed will give the desired spatial density coverage for the data collected by ALLTEM system.
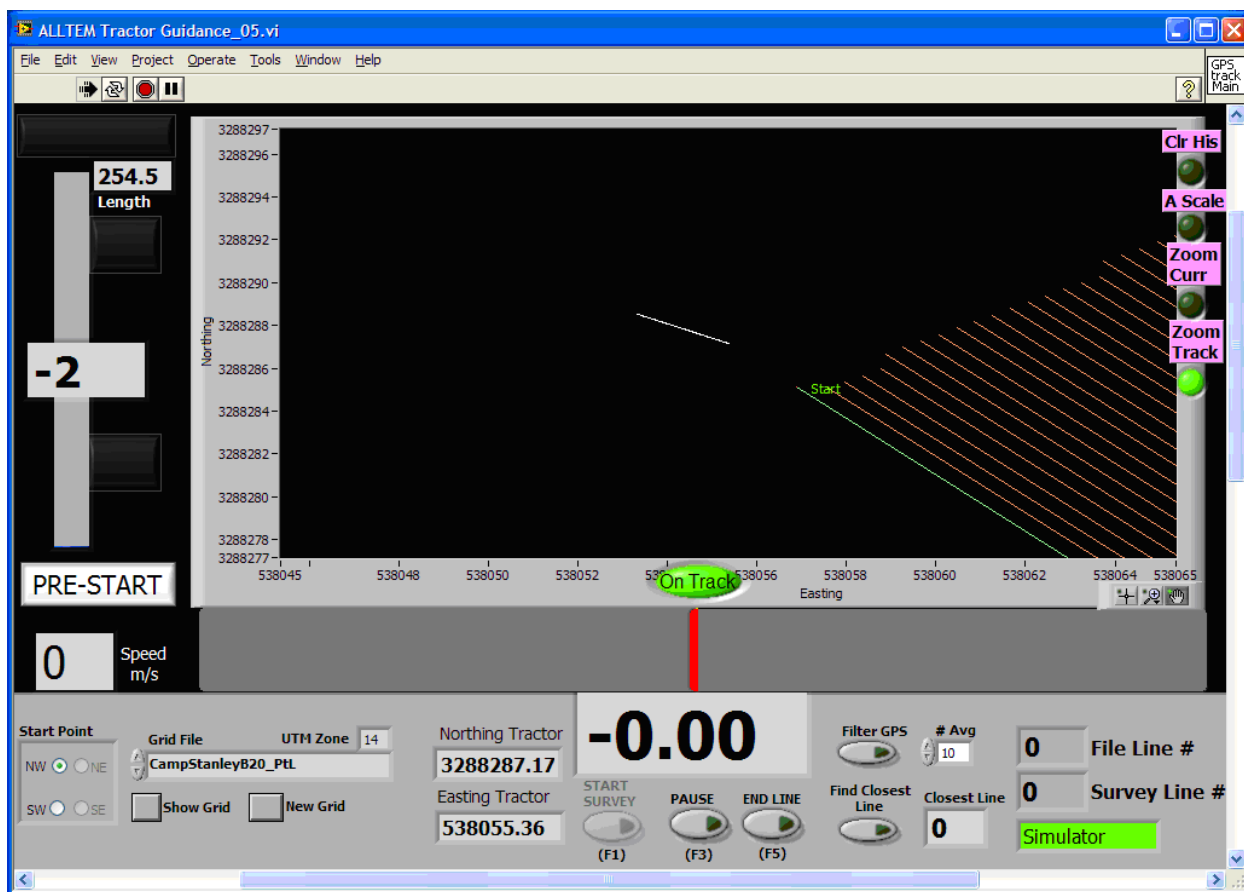
Figure 3.24. Main screen, after START SURVEY clicked, tractor is before the start of the line.
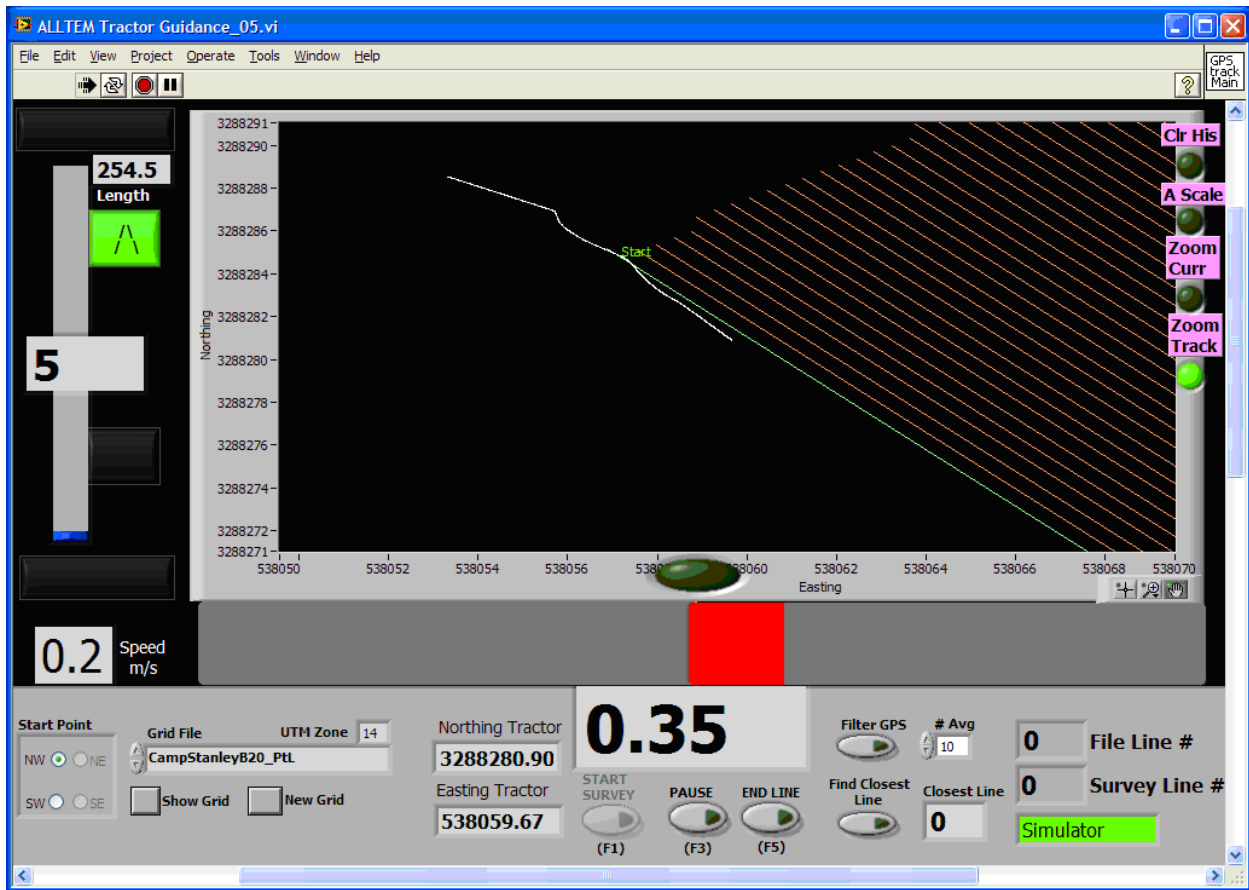
Figure 3.25. Main Screen, travelling left to right along line, after the beginning of the line.

At 1 meter/second, each of the three sequentially selected ALLTEM drive coils is on for equal periods, during every 20 cm of distance covered. Also on this screen, a green "up" arrow is visible on the left of the screen. This indicates that the tractor is travelling in the correct direction along the line. If the tractor was travelling in the wrong direction, a red "down" arrow would be visible on the lower left of the screen. In Figure 3.26 the tractor is "243" meters along the line, and is nearing the line end. The tractor is "-0.24" meters to the left of the line, indicating that the driver should steer to the right. In Figure 3.27 the tractor has past the end of the line. This is indicated by the status indicator, **POST-END**, in the upper right. It should be noted that this is the location of the GPS antenna mounted above the front axle of the tractor, not the location of the GPS antenna on the front of the ALLTEM cart. The back end of the ALLTEM cart is approximately 8 meters behind the tractor front axle. To make sure the ALLTEM cube gets past the end of the line, the tractor should be driven at least an additional 8 meters past the end of the line. In Figure 3.27, the tractor has driven approximately "10.5" meters past the end of the line (end of line at "254.5", indicator at "244"). Note that the distance along line indicator goes backwards from "254.5" once the end of the line has been reached. This is due to the way the program calculates this number. Once the distance has been reached, click **END LINE**. The **END LINE** operation can also be completed by a signal sent from the ALLTEM data acquisition software when **END LINE** is clicked on the data acquisition computer keyboard. The signal is sent through a serial cable between the two computers. Once **END LINE** is clicked, the program

will show the distance to the next line. In Figure 3.28, this distance is "-16.00" meters. The view of the survey has been auto scaled to show the entire survey area. This was done by un-selecting the **Zoom Track** mode button and then clicking the **A Scale** (auto scale) button once. In Figure 3.29, the tractor is lined up on the second line and has progressed 4 meters along it. Note again that this is the tractor front axle location. The front wheel of the ALLTEM cart is approximately 6.5 meters behind the tractor front axle.
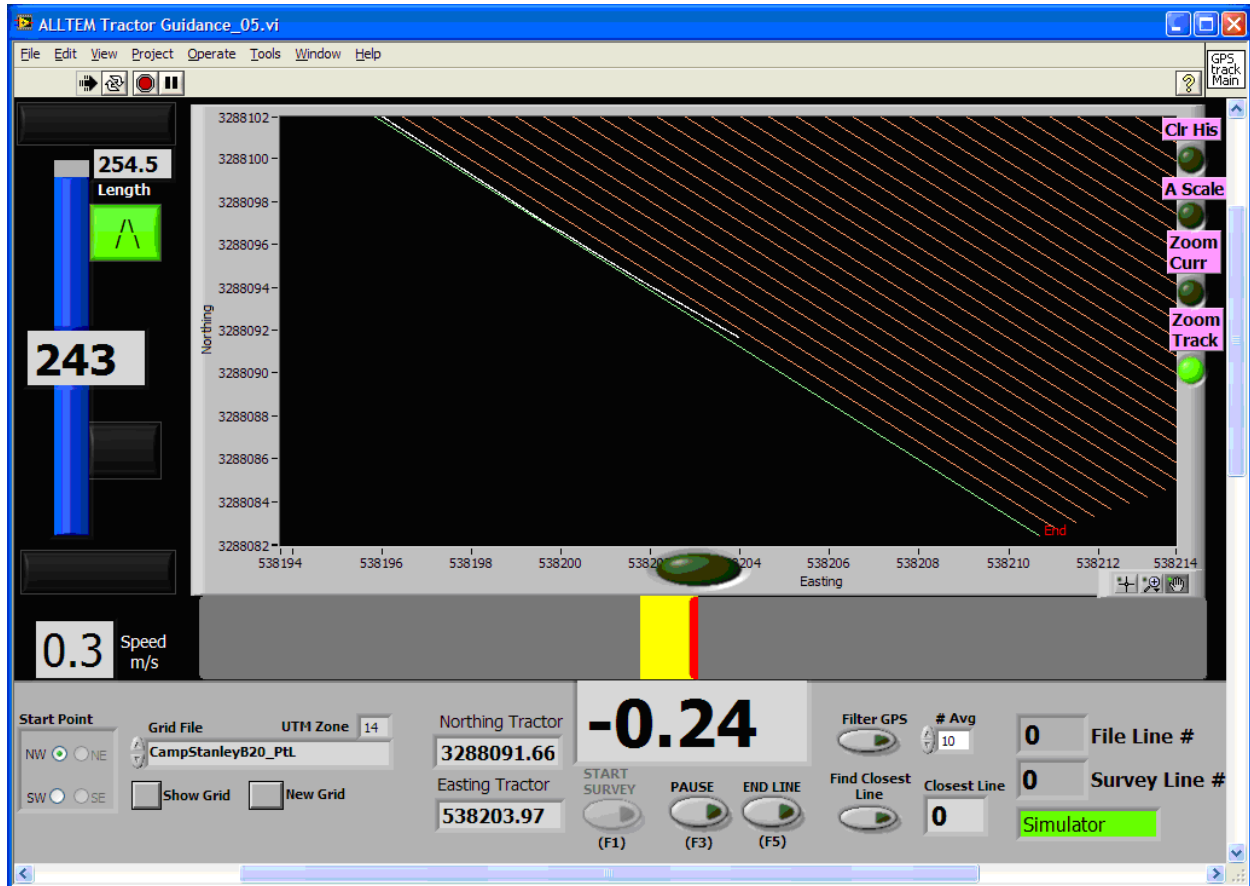
Figure 3.26. Main screen, tractor nearing the end of the line.
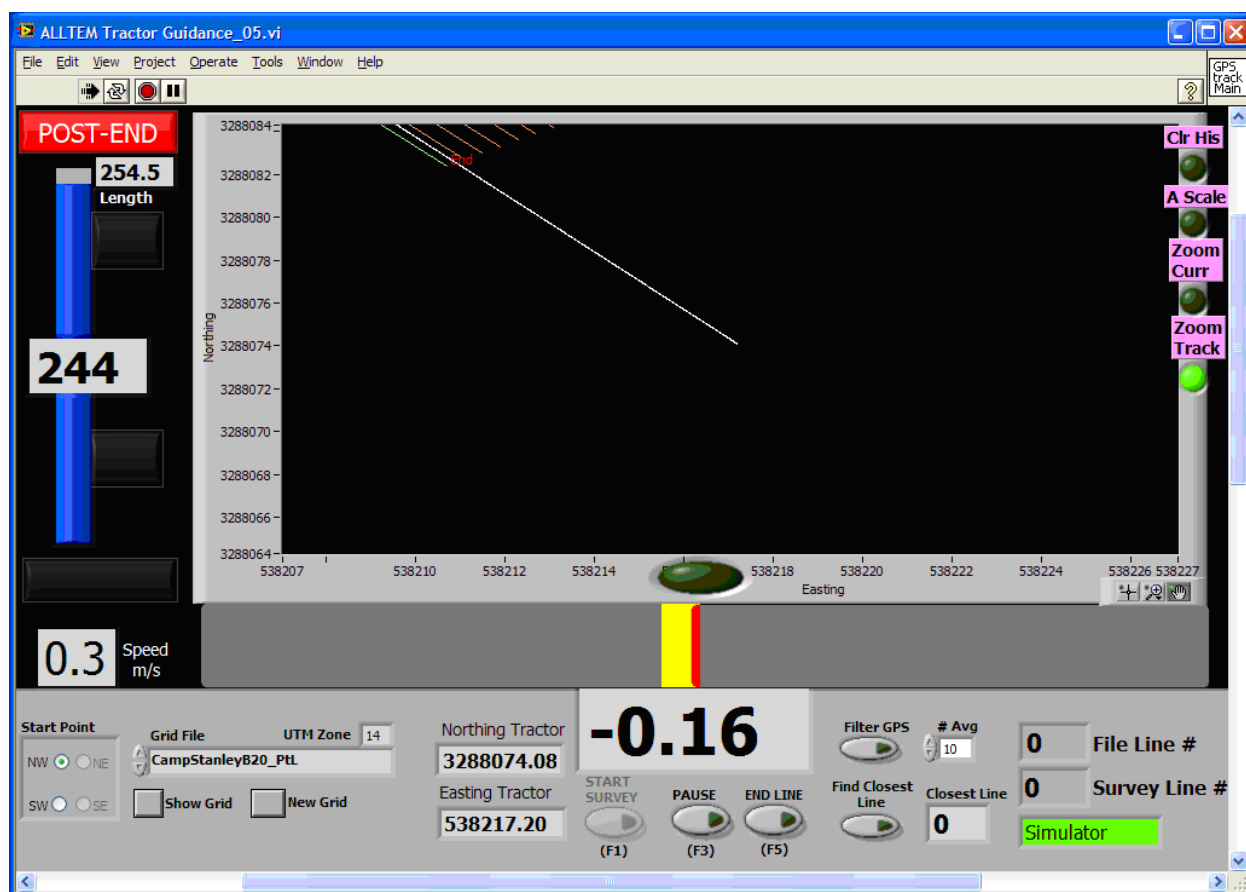
Figure 3.27. Main screen, tractor driven at least 8 meters past the end of the line.
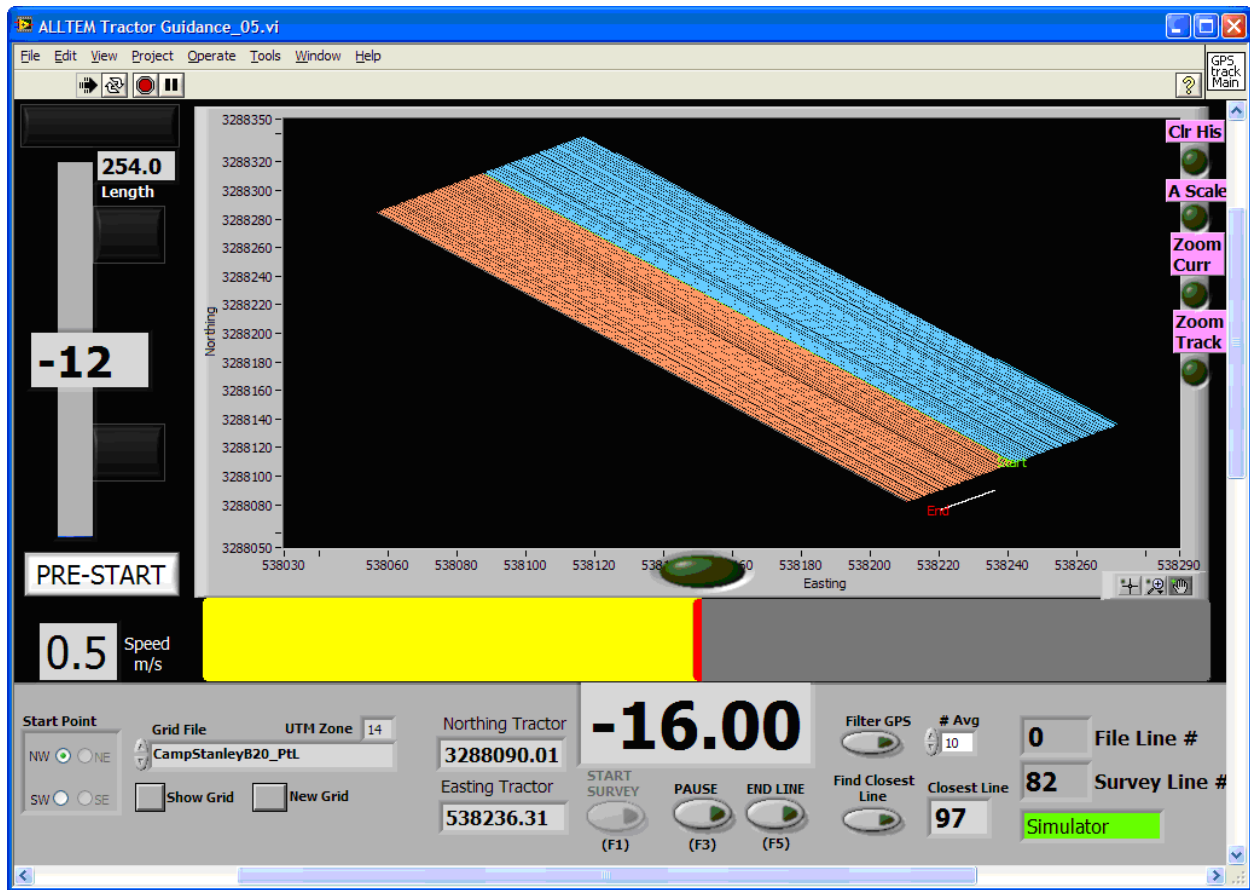
Figure 3.28. Main screen, END LINE clicked, Zoom Track off, A Scale once, driving to next line.
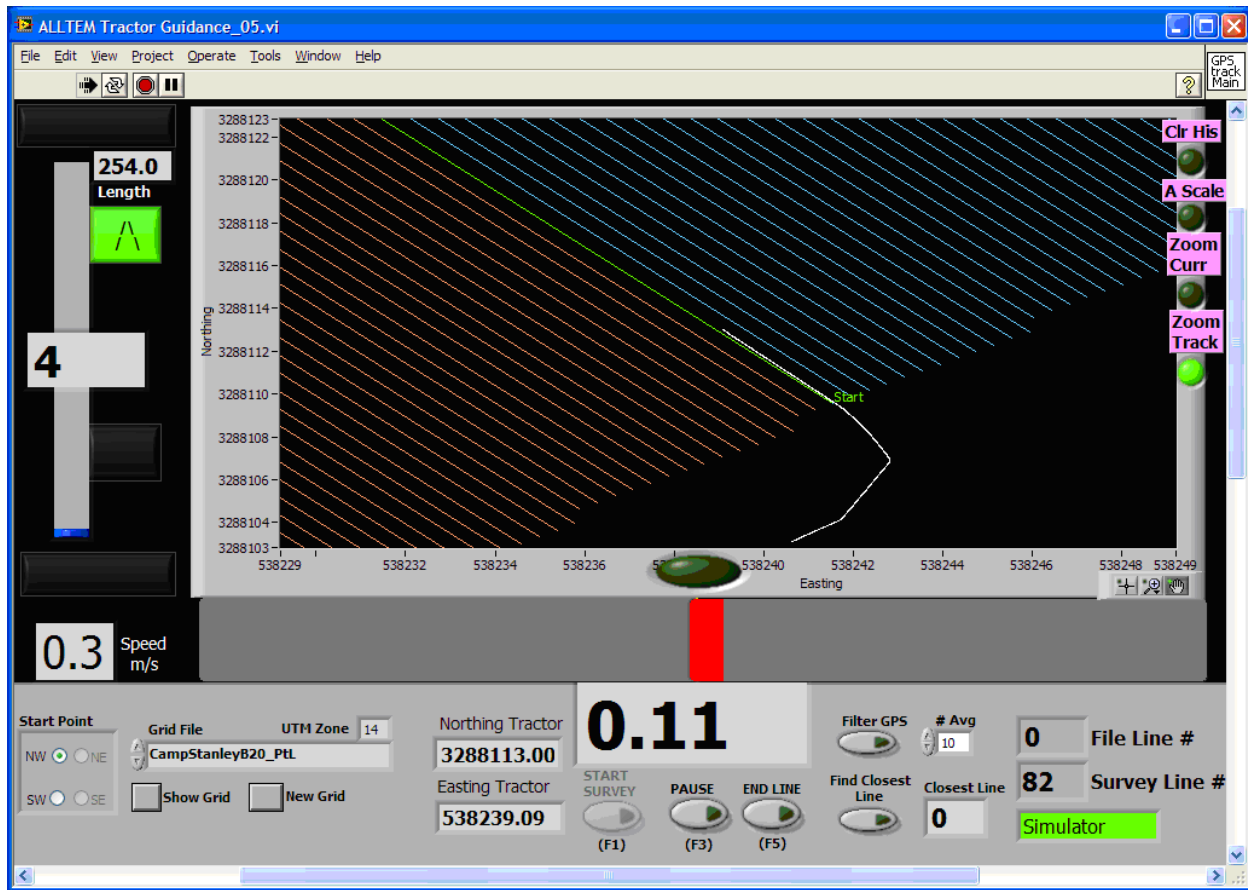
Figure 3.29. Main screen, Zoom Track on, lined up on next line and progressing along it.

3.4.5 PAUSE MODE

The **PAUSE** mode is used to allow the operator to highlight lines in the survey and determine the relationship between the survey line number and the file line number used by the data acquisition program, when saving data for a given survey line.

When determining file line numbers in the data acquisition program, it is important that they be named to correspond to the correct survey line number. Every time **END LINE** is clicked on the data acquisition program, it automatically increments to the next file line number, and this new file line number is sent to the Tractor Guidance computer. The Tractor Guidance program uses this number to determine the correct survey line number. If you name the file number in the data acquisition software incorrectly, the Tractor Guidance program will choose the wrong line as the current line in the survey.

Click **PAUSE** and additional controls will appear, as shown in Figure 3.30. The **Northing Begin** and **Easting Begin** are the beginning coordinates of the line selected with **File Line # Selector**. The **Northing End** and **Easting End** are the end coordinates of the same line. The "begin" and "end" labels might not correspond with the actual line beginning and end, depending on the value that **Start Line** was chosen as (**NW, SW, NE, SE**). The line being selected is

shown in white on the survey graph. The **File Line # Selector** value refers to the line number that this survey line would be saved as by the data acquisition program.
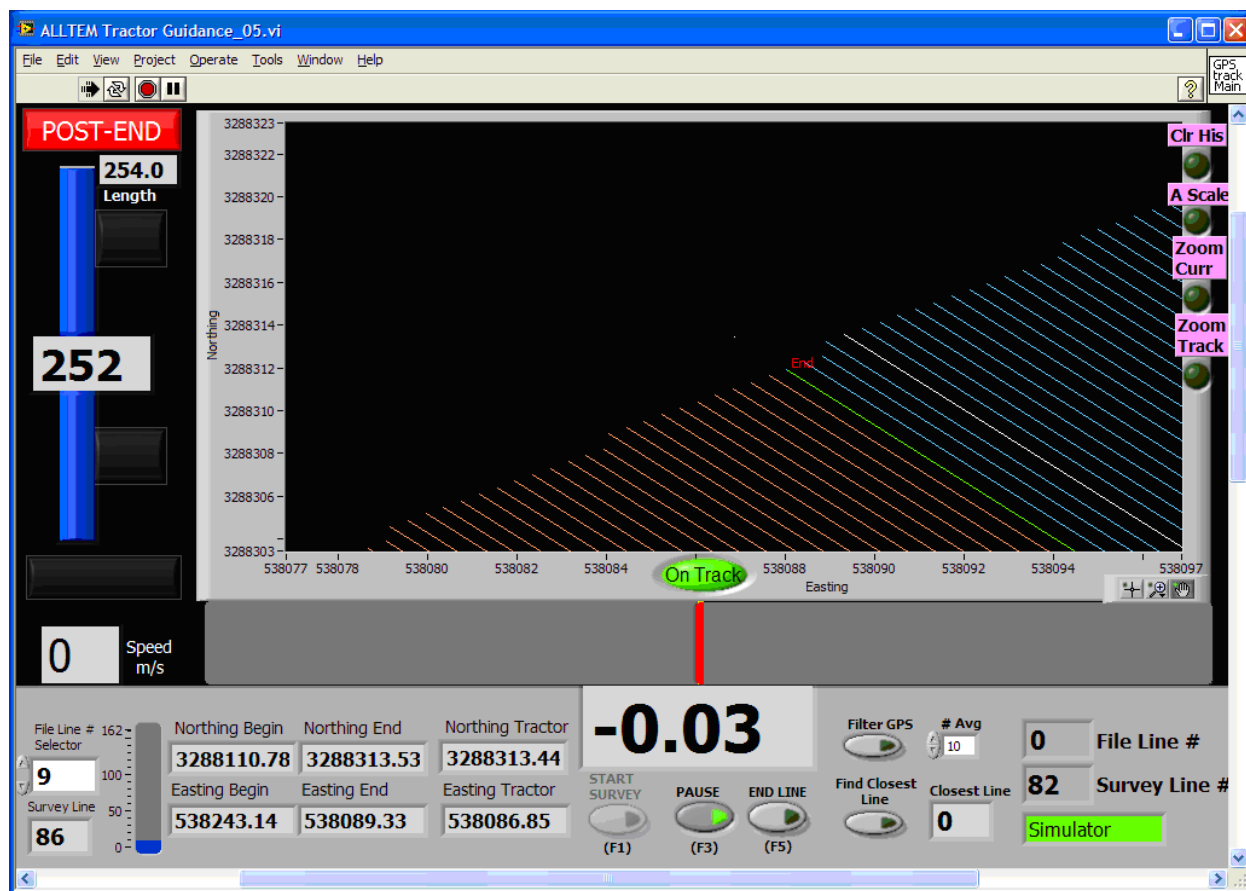
Figure 3.30. Main screen, Pause mode with selection of File Line # Selector 9, Survey Line 86.
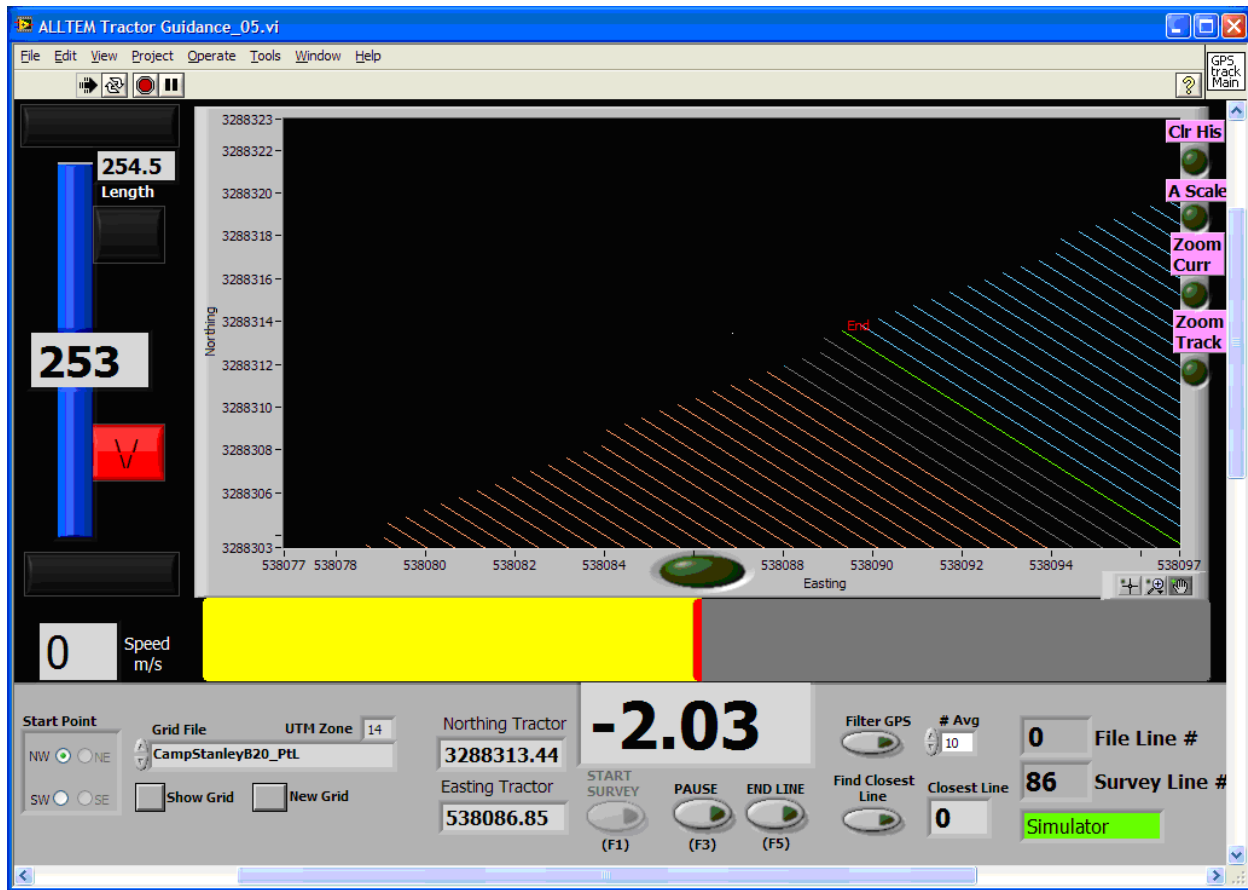
Figure 3.31. Main screen, using END LINE to adjust the current line to Survey Line # 86

Each advance of this value will move the selected survey line to alternating halves of the survey area, just as would happen when the lines were being saved with the data acquisition program. The lines in the survey are sequentially numbered from 0 to the last line in the survey. To use this control, determine which file number you are trying to acquire and set the **File Line # Selector** to this value ("9" in the example). The corresponding survey line number is shown in the **Survey Line** indicator below ("86" in the example). If you want to adjust the current line of the survey to these values, exit the **PAUSE** mode and click the **END LINE** button until the **Survey Line #** indicator (bottom right of screen) indicates "86", see Figure 3.31. After each **END LINE** button click, the color of the previous line in the graph will turn a light grey, and the next line turn will turn green. The light grey lines indicate that these lines have already been surveyed. Currently, the **END LINE** button only increases the line numbers in the survey, there is no way to go backwards. If you overshoot the line you are trying to set with the **END LINE** button, you must restart the program and try again.

3.4.6   FIND CLOSEST LINE

This function can be used if you want to find the survey line that is closest to the current position of the tractor. This could be the case if a survey could not be completed in a single day, and the next day, the ALLTEM tractor had to be lined up to continue the survey where it had left off.

The function works best if the tractor is being driven just off of the survey area, near the end points of the lines. Click **Find Closest Line** and the **Closest Line** will indicate the closest line to the current tractor position. In Figure 3.32, the closest survey line to the tractor is number 90. This is the survey line number, not the corresponding file line number that it would be saved with during an actual survey.
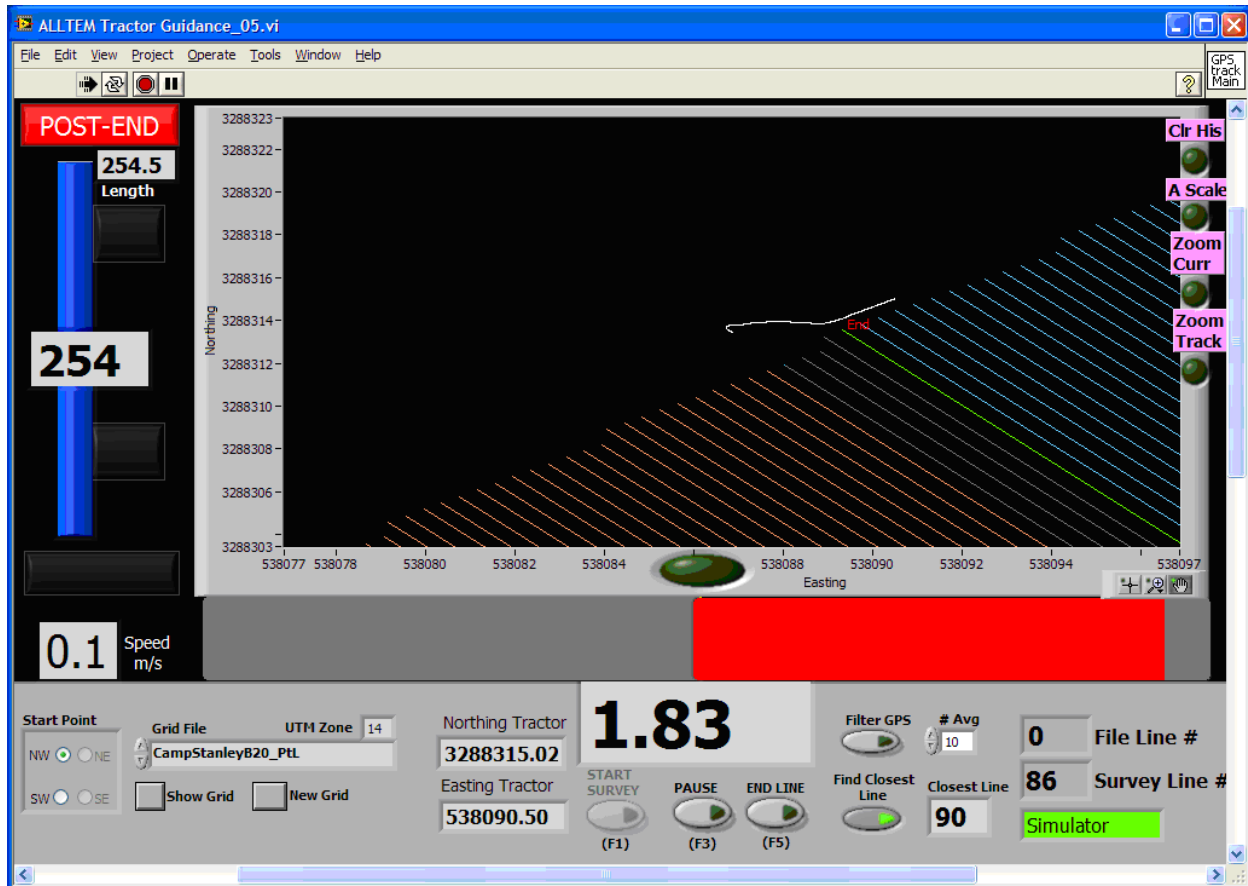
Figure 3.32. **Main screen,** using the Find Closest Line control. The closest survey line to the current tractor position is 90. The last tractor position is at the right end of the white line. The survey line counting starts at line 0.

3.4.7   FILTER GPS STREAM

The **FILTER** control can be used to filter the stream of GPS values being acquired by the laptop. For the Leica GPS unit, the GPS values are updated every 50 mS. This may cause the line position error value to jump around unacceptably if the GPS values are not stable. To reduce this effect, click the **FILTER** button. The number of values that are used in the filter can be adjusted with the **# AVG** control. In Figure 3.32, this value is set to 10 samples. Setting the value too high could cause unacceptable lag in the response of the line error display.

3.5   Summary of Context-Sensitive Pop-Up Help Notes

Context-sensitive help is available on screen.   Help notes are selected by moving the cursor to the area where help is desired. The help pop-ups may slow the program and after familiarization they may no longer be needed. They can be toggled "off" and "on" by using the CTRL-H key combination or by selecting Help on the task bar and toggling the Show Context Help control.

1.   # Avg: This controls the number of GPS values used in the "rolling average" filter when Filter GPS is selected.
2.   Auto Scale: Use this to auto scale the survey graph to a size that will include the entire survey, plus the history of the tractor path (white line).
3.   Clear History: Used to clear the path history (white line) on the survey graph. The history is cleared automatically on a periodic basis to keep the graph from becoming too cluttered.
4.   Closest Line: When the Find Closest Line control is enabled, this indicates the closest survey line to the current tractor location.
5.   Correct Direction Indicator: When lit, indicates that the tractor is travelling in the correct direction towards the end of the line).
6.   Distance Error Indicator (Negative): Bar graph showing the current NEGATIVE value (shown in Yellow) of the Distance Error Value display. Negative values mean the driver should steer right. Positive values are shown in red on the Distance Error Indicator (Positive) bar graph.
7.   Distance Error Indicator (Positive): Bar graph showing the current POSITIVE value (shown in Red) of the Distance Error Value display. Positive values mean the driver should steer left. Negative values are shown in yellow on the Distance Error Indicator (Negative) bar graph.
8.   Easting Begin: While in the PAUSE mode, this indicates the Easting beginning coordinate of the survey grid line selected with the File Line # Selector. The beginning and end designations are only used to differentiate the 2 points that define the line.
9.   Easting End: While in the PAUSE mode, this indicates the Easting end coordinate of the survey grid line selected with the File Line # Selector. The beginning and end designations are only used to differentiate the 2 points that define the line.
10.   Easting Tractor: Indicates the current UTM Easting position of the tractor.
11.   END LINE: Use to end the current line and advance to the next line in the survey. When this is selected, the current line color will turn light grey and the next line will turn green. When selected from the Tractor Guidance program, only the Survey Line # indicator will change. When selected from the data acquisition program, the File Line # display will also change. The F5 function key will also end the line.
12.   File Line # Selector: While in the PAUSE mode, used to view select lines in the survey grid. The selected line appears as white on the Survey Graph. The File Line # number control indicates the file number that the associated Survey Line should be saved as, in the data acquisition program.
13.   File Line #: This indicates the current file line number being used by the data acquisition program. It is sent to the Tractor Guidance computer over a serial line and updated

when END LINE is selected on the data acquisition program. It is NOT updated when END LINE is selected on the Tractor Guidance computer.

14. Filter GPS: Use this to filter the GPS values being received by the Tractor Guidance computer. This may reduce unwanted variability in the Northing and Easting displays and the Line Error Display. The filter is a "rolling average" type and the number of GPS values in the filter is set by the # Avg control.

15. Find Closest Line: Use this to enable displaying the closest survey line to the current location of the tractor. The closest line is displayed in the Closest Line display. The function works best when the tractor is near the end of the survey lines. It may give incorrect values when further away from the ends.

16. GPS Status: This indicates the current status or error condition of the GPS being received by the Tractor Guidance computer. Status messages are : SPS, DIFFER, RTK_FL, RTK_FX. GPS error messages are: Bad Mode#, NON GGA, SERIAL TIMEOUT, and NO GPS. When the GPS simulator is being used, the status will indicate Simulator.

17. Line Length Indicator: Shows the length of the current line in meters.

18. Northing Begin: While in the PAUSE mode, this indicates the Northing beginning coordinate of the survey grid line selected with the File Line # Selector. The beginning and end designations are only used to differentiate the 2 points that define the line.

19. Northing End: While in the PAUSE mode, this indicates the Northing end coordinate of the survey grid line selected with the File Line # Selector. The beginning and end designations are only used to differentiate the 2 points that define the line.

20. Northing Tractor: Indicates the current UTM Northing position of the tractor.

21. On Track: This indicates when the tractor's current location is within +/- 10cm of the current line being surveyed.

22. PAUSE: Use to pause the updates to the Survey Graph and display the survey line viewing controls on the left of the screen. The F3 function key can be used to toggle in and out of the pause mode.

23. POST-END: Indicates that the tractor is located after the end of the current line.

24. PRE-START: Indicates that the tractor is located before the start of the current line

25. Progress Along Line Indicator: Shows the progress along the current line in meters. The associated bar graph shows the progress as a percentage of the entire line length. After the end of the line, the value decreases from the line length value.

26. Speed Indicator: Shows the speed of the tractor in meters/second. The speed is calculated from the GPS values being received by the Tractor Guidance program.

27. START SURVEY: Use to start the survey, after the Grid File and Start Point have been correctly chosen. The F1 function key will also start the survey.

28. Survey Graph: Shows the survey lines and history of the tractor positions. The survey lines are reddish-brown for south going lines and light blue for north going lines. This direction scheme is not true for survey lines that are purely east to west.

29. Survey Line #: This indicates the current survey line number in use. The survey lines are numbered sequentially, starting at line 0.

30. Survey Line: While in the PAUSE mode, indicates the Survey Line # associated with the value selected with the File Line # Selector control.

31. Wrong Direction Indicator: When lit, indicates that the tractor is travelling in the wrong direction (away from the end of the line).
32. Zoom Current: Use this to zoom the survey graph to the current location of the tractor. The zoom will only take place once. To continually keep the tractor position in the center of the graph, choose Zoom Track.
33. Zoom Track: Use this to continually center the survey graph view on the current position of the tractor.

4.0 ALLTEM NULLING SIMULATOR SOFTWARE

4.1 Purpose

This ALLTEM system nulling software simulator is a training tool to prepare an operator for actual operation of the ALLTEM system. A complete description of the principles underlying nulling is given in section 2.1 above.

4.2 Operation of ALLTEM Nulling Simulator

Launch this program by double-clicking on the icon "ALLTEM System Nulling Simulator.vi" shown in Figure 4.1

Figure 4.1. The ALLTEM System Nulling Simulator icon.

The first screen that will come up is called **SETUP BEFORE STARTING NULLING**, Figure 4.2. At the top of the left window is text line that says, "Contents of C:\ALLTEM System Settings\System Nulling Files". Below this line is a list of nulling files with name, size, and date modified shown. Select the one you want to use and double-click on it. If you have not previously stored a nulling file and have no basis on which to select a file, select the "Default.nul" file. In this example a file named "Test.nul" is shown selected. A note associated with this file is displayed in the **Nulling File Information** field. Later, when you store your own nulling file, you will be presented with the option of entering a note about your nulling file. Any note you write will be stored as a header in your file and displayed in this field when you highlight the file.
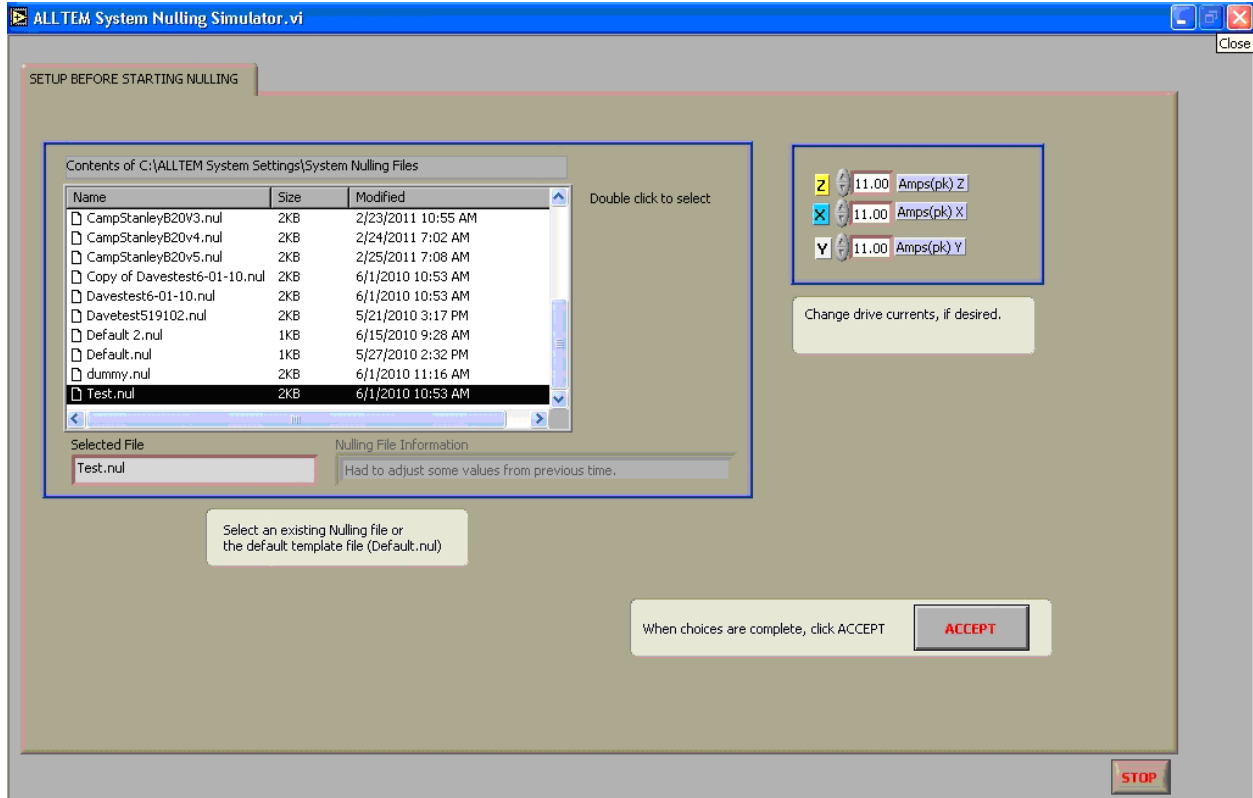
Figure 4.2. The **SETUP BEFORE STARTING NULLING** screen. Nulling file names, drive coil currents, and buttons to **ACCEPT** or **STOP** are shown.

The smaller frame in the upper right contains buttons and fields for setting the drive current peak amplitudes for each of the three TX coils. The range is 0 to 11 amperes. The up/down buttons can be clicked to adjust the current in 1 ampere increments for the corresponding coil. Alternatively, a current value can be typed in any of the three windows. Normally, these currents are left at their maximum (11) settings. In rare circumstances it may not be possible to null the system at the maximum 11 ampere setting, as when the current drive amplifier begins to clip or overheat in extremely hot environments. The system has successfully operated in the field for extended periods at the maximum current settings in ambient temperatures up to 41 degrees C (106 degrees F).

After all selections are made, click on the **ACCEPT** button which will bring up the **SYSTEM NULLING** screen, Figure 4.3. This screen has three tabs, **SYSTEM NULLING**, **SAVE**, and **NOTES**. The descriptions that follow will work through this screen in the order of the numbers indicated, which is also the order in which the program should be used, although some steps may be omitted if not needed. At the left, there is a **Message** field. This will contain information needed for certain combinations of DRIVE (TX) coils and SENSE (RX) coils. At the lower left is a **Block Diagram** frame. This frame is for illustration only. No values can be entered or altered within this frame. Notes 1 and 3 can be found by selecting the **NOTES** tab. As discussed above, what is being done when nulling is that SENSE (RX) coil pair relative gains and offsets are being adjusted to keep the differenced voltages from the various RX coil pairs within the maximum voltage ranges of the subsequent analog amplifiers and digitizer input. Ideally, when

the system is not over a target, the RX voltages for all polarities would be zero. The objective is to adjust the system so that all voltages are as close to 0 as possible. The voltages levels at the locations of the yellow and pink cursors are shown in the fields below the waveform screen and ideally should be adjusted to be zero.
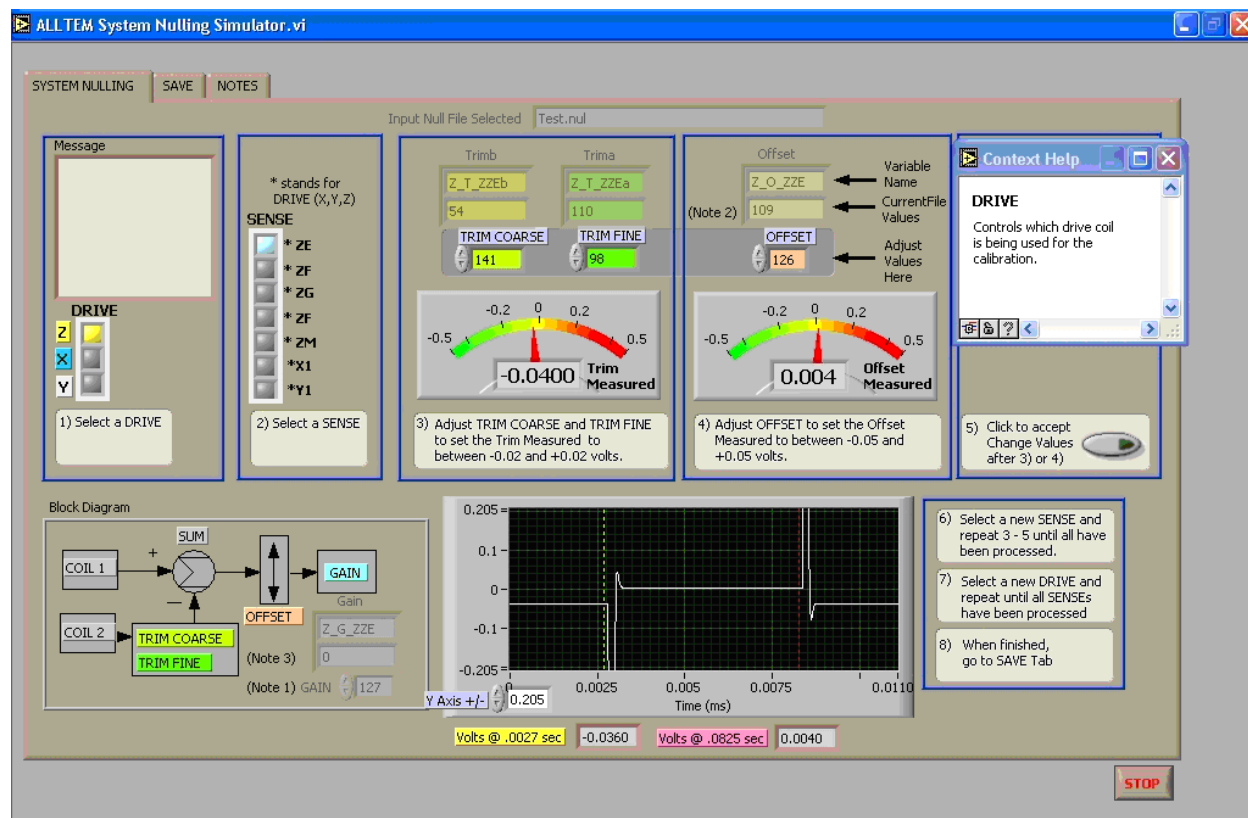
Figure 4.3. The **System Nulling Screen** where amplifier trims and offsets are selected. There is context-sensitive help available on screen (for example, the pop-up window in the upper right of the screen). Help notes are selected by moving the cursor to the area where help is desired. The help pop-ups are optional and can be toggled "off" and "on" using the CTRL-H key combination.

Step 1: Select the drive coil to be used by clicking on its square button. In this example the Z-coil (the horizontal coil that produces a vertical magnetic field) is shown selected. Selections can be done in any order, but the straightforward way is to select these from top to bottom. It is always possible to come back to any particular combination of TX coils and RX coils to double check the quality of the nulling.

Step 2: Select a SENSE. A column of 7 buttons corresponds to each of RX coil pairs. Multiplying by the three possible DRIVE coil polarizations, there is a total of 21 possible TX/RX combinations. Not all of these are useful. The names and configurations of the useful polarizations are shown in the ALLTEM system hardware manual. When a combination is selected that is not useful, a message will appear in the **Message** field stating that this combination is not used and no attempt should be made to adjust it. Two combinations (ZX1

and ZY1) must be nulled manually with potentiometer adjustments. These two cases are discussed below. A straightforward approach is to select the SENSE buttons from top to bottom. It may be discovered that some polarizations are more prone to drift than others. After the first adjustment, any combination can be reselected and readjusted before saving the nulling file or on subsequent openings of that file.

Step 3: Adjust **TRIM COURSE** and **TRIM FINE** to set the **Trim Measured** meter to between - 0.02 and +0.02 volt. Simply click on the up-down buttons, first the coarse and then the fine, to bring the resulting voltage as close to zero as possible. The TRIM COARSE and TRIM FINE adjustments change the value of a digitally controllable potentiometers on the ALLTEM_ SumScaleFlt boards. The potentiometer is in parallel with another resistor on the board. Because of this configuration, changes to the value of the digital potentiometer do not change the Trim values in a linear fashion. The Trim values near the top of the range (near 255) will not affect the Trim values as much as values near 0. A good technique is to place the TRIM FINE value near 100 and then adjust TRIM COARSE until the value in the Trim Measured meter just transitions from positive to negative or negative to positive values. Then, if necessary, adjust the TRIM FINE control to get the Tim Measured closer to zero. The selected values appear in a window for coarse and fine ("54" and "110" in this example). The "Trim B" (coarse value) and Trim A" (fine value) variable names that will be stored in the nulling file are shown in the top windows in this frame. These names are not editable. As may be deduced, these variable names are descriptive. In this example "Z_T_ZZEb" indicates that the stored value contains information for the vertical polarization (Z) trim (T) using the particular ZZE drive/sense combination and that the value stored is a coarse "b" trim setting.

Below the meters is a waveform display panel. This can be used along with the meter to adjust the waveform to be as close to zero as possible. The waveform shown in the waveform display is the RX response during one cycle of the 90 Hz triangle coil drive signal (0.0111 ms). The waveform shown is a digitally created simulation of an actual ALLTEM waveform. An actual ALLTEM waveform would have more noise in the signal. The two large "spikes" (one positive, and one negative) correspond to the two corners of the triangle wave cycle. All measurements made with the nulling program are made after the effects of the "spike" voltage have died out. Referring to the waveform display in Figure 2.3, the voltage shown in the Trim Measured meter is calculated by subtracting the waveform values at the yellow and pink cursor points from each other. The value in the Offset meter is the value of the waveform voltage at the yellow cursor. The sensitivity on the voltage (vertical) scale can be selected with the **Y Axis +/-** button. .

Step 4: Offset adjustment allows a voltage offset to be entered. The resulting range after course and fine trim and voltage offset adjustments should lie between – 0.05 and + 0.05 volt, as registered on the meter. As shown, it is often possible to get both the trim and offsets well within the maximum range limits.

Step 5: **NOTE!** The adjustments made in steps 3 and 4 will **not** be stored until the **Press to accept Change Values** button is clicked, so when the values you have for trim and offset are the best you can achieve, **click this button before going to the next sequence.**

Steps 6 and 7: Repeat the above steps for all three drive coils and all seven sense coil pairs. Some exceptional cases will be flagged in the **Message** field. We show an example in Figure 4.4. A message in the **Message** field states: "ZX1 can't be set with TRIM adjustment. To set TRIM, adjust Potentiometer, R19, on the ALLTEM_SumScaleFlt PWB. See NOTE Tab for picture of R19." For this case the trimming must be done using a mechanical potentiometer, R19, on the ALLTEM_SumScaleFlt printed wiring board (PWB). The "ZY1" also requires manual adjustment of a potentiometer, R129. The message also directs the user to the **NOTES** tab (Figure 45). "YX1" and "XY1" are not meaningful and are flagged.

Step 8: When all combinations have been nulled, go to the **SAVE** tab (Figure 4.6).

Step 9: Name the new nulling file. The "nul" file name extension is automatically appended. A comment can be included.

Step 10: The last step is to save the new nulling file by clicking the button. **Failure to do so will cause no new nulling file to be saved.**

This completes the simulation procedure for adjusting voltage trims and offsets for all polarities.
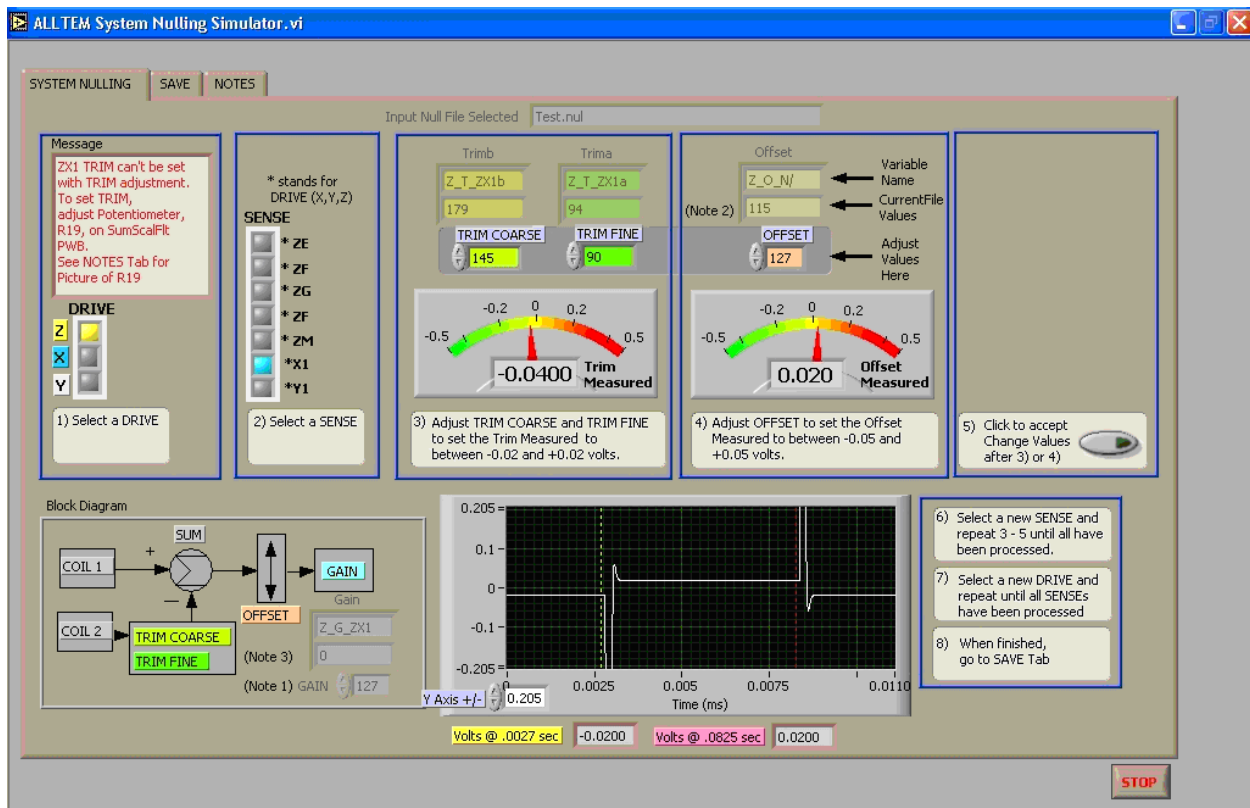
Figure 4.4. If this message comes up it should be ignored. The ZX1 TX-RX coil combination can now be adjusted electronically. The message directs the user to potentiometer R19 and the **NOTES** tab.
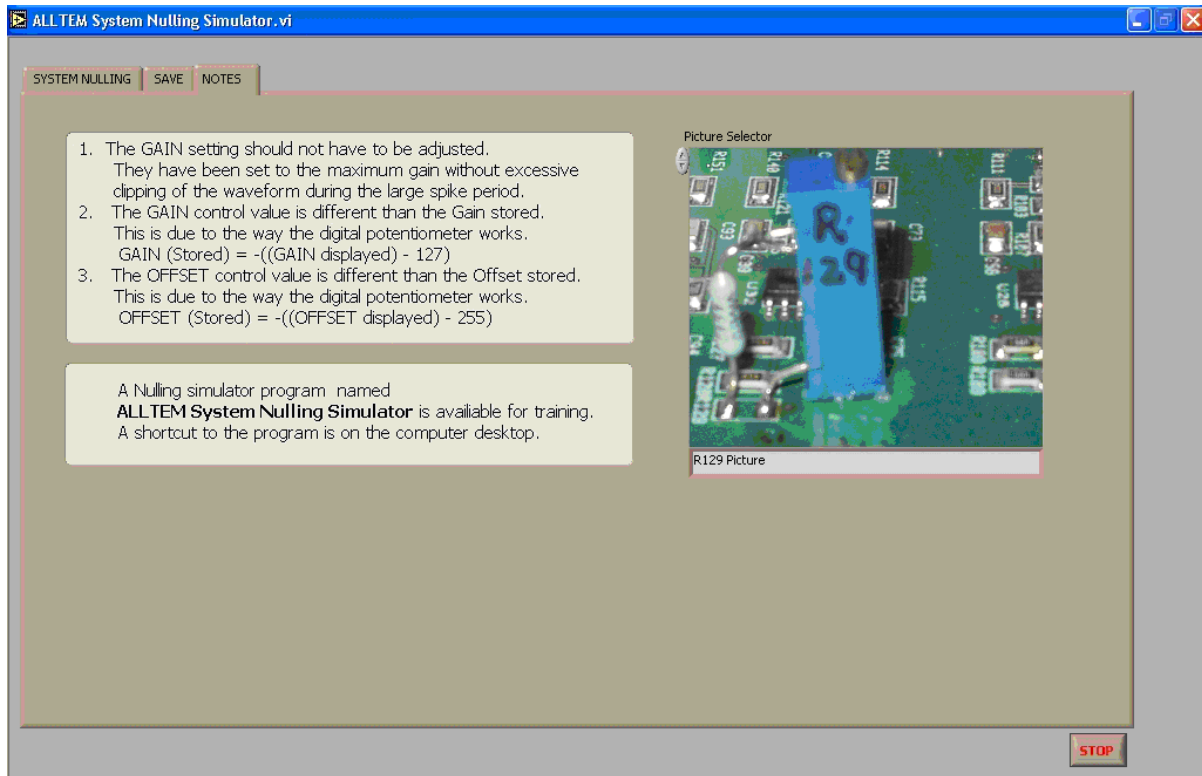
Figure 4.5. The NOTES tab with a picture of potentiometer R129.
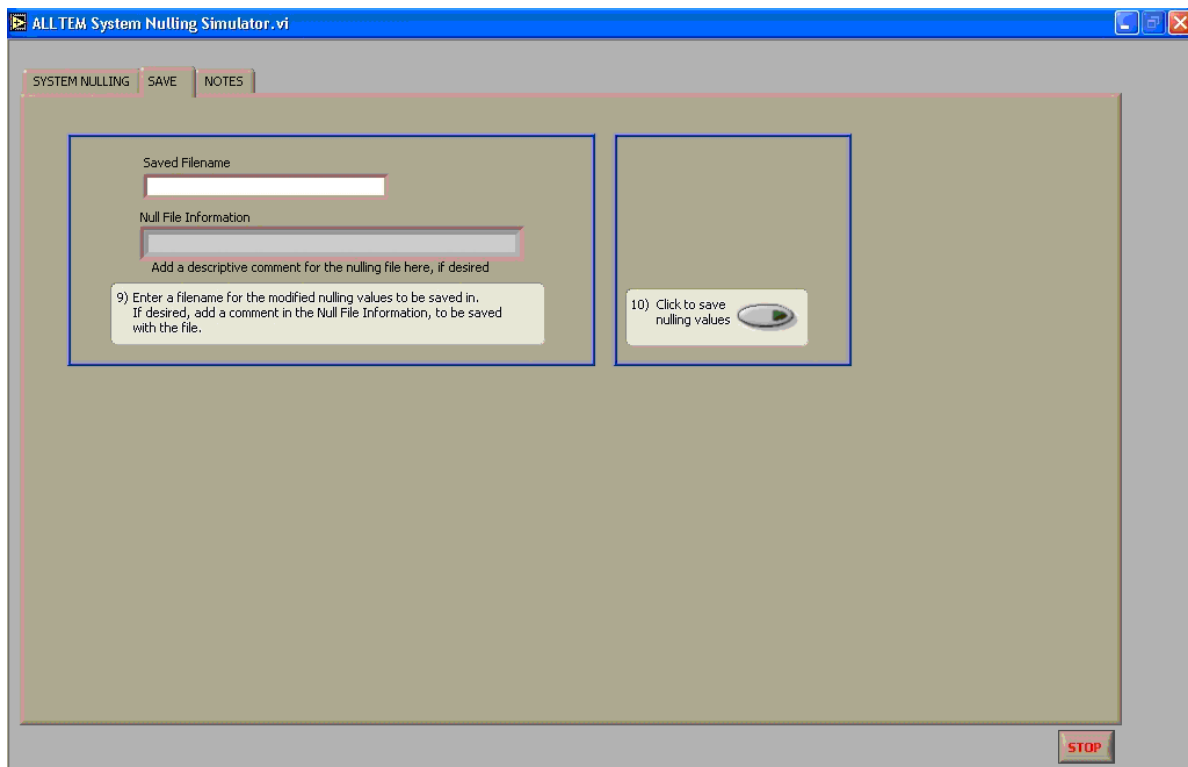
Figure 4.6. The **SAVE** tab with instructions.

5.0   DATA ACQUISITION SIMULATOR SOFTWARE

5.1   Purpose

This program is a training tool that can be run independently of the ALLTEM system. It simulates the operation of the data acquisition software including digitizing and recording of all needed information. It does this by reading a furnished subset of actual recorded field data. The software simulates automatic sequencing of the three orthogonal TX coils and the various combinations of RX coil pairs. It simulates digitizing of analog voltages from each sequenced TX-RX coil combination. Digital data are output with the file names and headers that will identify the information needed by the subsequent data preprocessing software.   Header information includes the position information from the global positioning system (GPS) and the Attitude Heading Reference System (AHRS) data.

5.2   Using the Data Acquisition Simulator Software

The simulator and a practice set of field data must be installed.

To launch the program, double-click on the icon called "ALLTEM Data Acquisition Simulator" as shown in Figure 5.1.

Figure 5.1. ALLTEM Data Acquisition Simulator Program icon.

The opening screen will be a front panel like the one shown in Figure 5.2. Click the Run arrow icon in the top menu bar to start the program. This will bring up the setup screen shown in Figure 5.3.
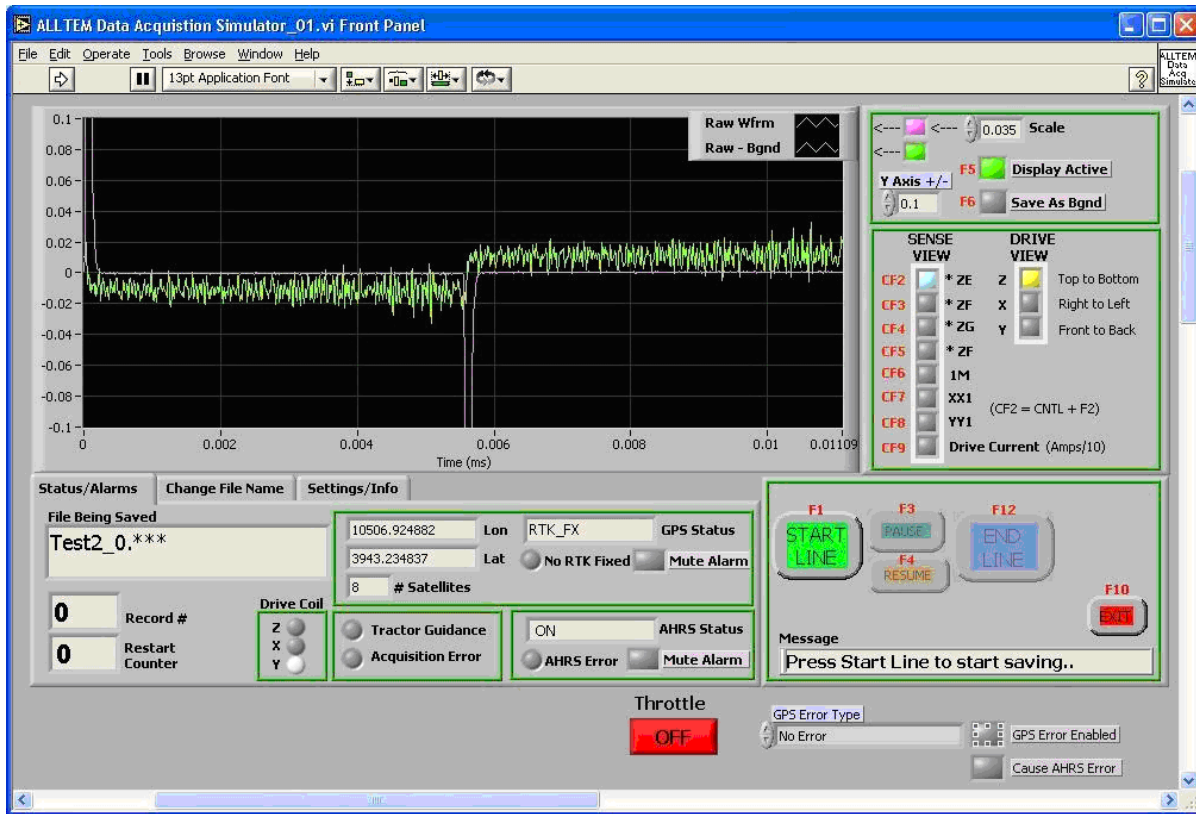
Figure 5.2. The **Simulator Front Panel**. To start the simulator, click on the run arrow icon on the menu bar at the upper left.
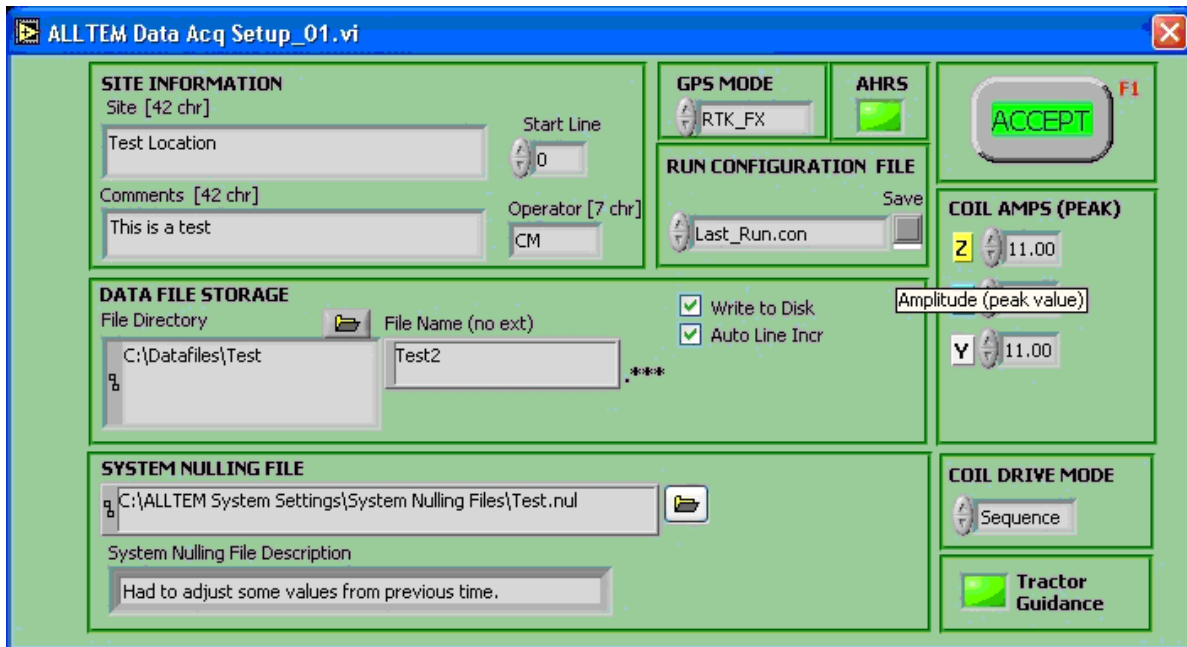
Figure 5.3. The **Data Acquisition Setup** screen controls a number of parameters, information and file names.

In the **SITE INFORMATION** frame are three fields into which information may be typed. The **Site** field allows information about the site to be entered. This field has a limit of 42 characters, as indicated. The **Comments** field allows entry of any other information the operator might want to save. This field is also limited to 42 characters. The third, **Operator**, field allows entry of the operator's identification with a 7 character limit. The **Start Line** button allows the operator to specify a starting line number other than the default "0". This would be useful for cases where a large area had been only partially covered on a previous run and it is desired to resume data collection with the next line number. An integer number between 0 and 999 can be selected by the up/down button or manually typed into the field.

The **DATA FILE STORAGE** frame shows the directory into which the data file will be saved. The data file name can be changed by clicking in the **File name (no ext)** field and typing a new or modified name (without extension). If it is desired to store the data files in a different directory, click on the browse icon to the right of **File Directory**. This will bring up the directory into which data files are currently being stored, Figure 5.4. You may select a different directory. The standard Windows operations also permit creation of a new folder.
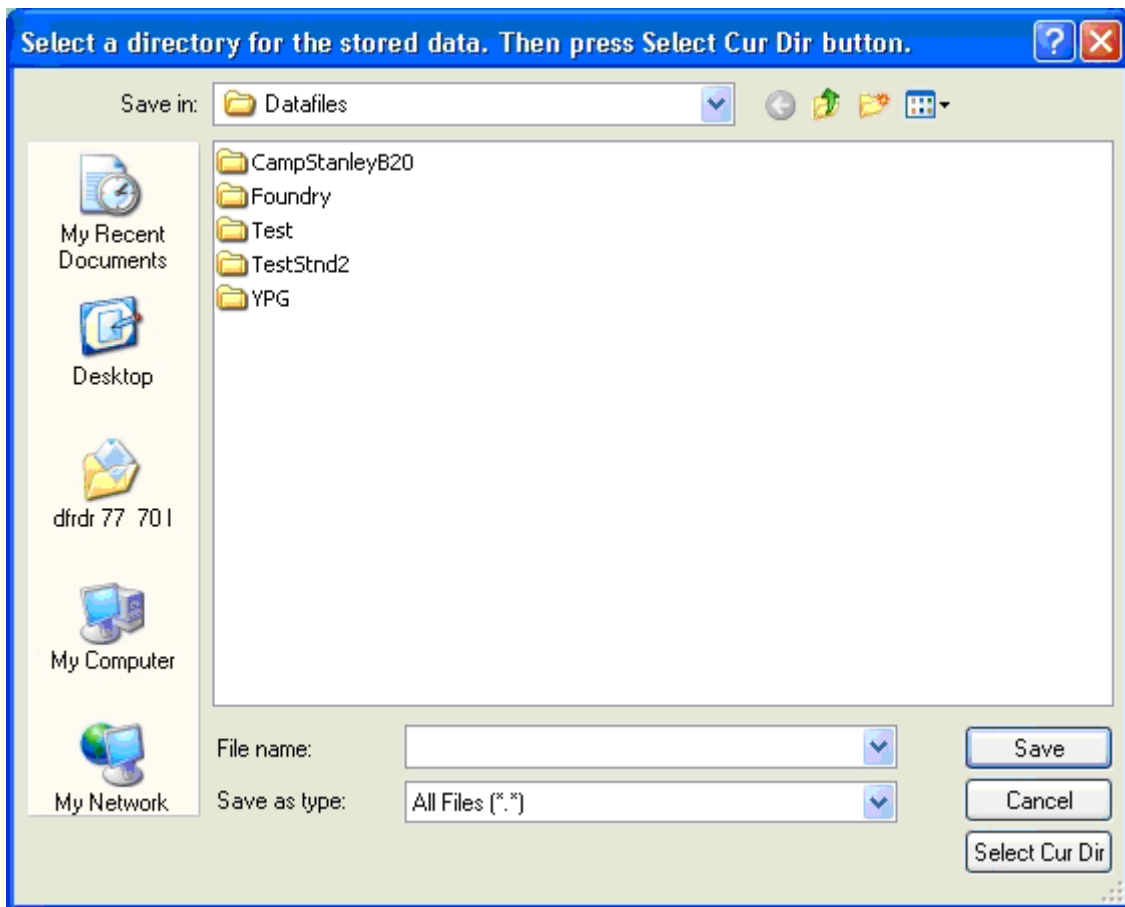
Figure 5.4. An example "Datafiles" directory. From this folder you can move to a subfolder and select it for use by clicking on the **Select Cur Dir** button at the lower right. The standard Windows operations also allow creation of other folders for use.

To the right of the **File Name (no ext)** field (Figure 5.3) are two control boxes that may be checked or unchecked. During normal data operations where data are to be stored, be sure to check the top box **Write to Disk**. The **Auto Line Inc** control, if checked, automatically creates a sequence of data file names corresponding to each line of stored data. For example, if data are being stored in files that begin with "test01" the sequence would be "test01_0.xxx, test01_1.xxx, test01_2.xxx, and so on, where the "xxx" extension refer to the identifiers for the various TX-RX coil combinations that are being recorded, as discussed in the ALLTEM equipment manual. It is suggested that this control be checked. If not checked, data would go into a single file that could get very large. A risk of putting all field data into a single file is that if the file gets corrupted and cannot be read, a great deal of time and data could be lost. Data files written by the simulator are replicas of recorded field data.

The **SYSTEM NULLING FILE** frame shows the nulling file (refer to section 2.0 in this manual) that is being used and any comments that were entered into the header of that file. The browse icon will take the operator to the directory in which various nulling files have been stored. A different nulling file may be selected. If a different nulling file is selected and the **ACCEPT** button is clicked, the newly selected nulling file will be used not only for the current use of the program, but also for all subsequent uses of this program, until changed again by the operator.

The **GPS MODE** frame in this example shows "RTK_FX." See the GPS operation part of this manual for definitions of the various modes of operation. Note, however, that for reliable inversions of the data to get target physical parameters and classifications, accurate positional information (within +/- 5 cm) is required. The only GPS mode that can provide such accuracy is the Real-Time Kinematic Fixed (RTK-FX) data quality. Fixed means that the GPS signal phase information is being used, that is, there is no cycle-slipping. For short drop-outs the system reverts to a predictive algorithm that may or may not be within the required accuracy. We will discuss GPS further in the discussion of the next screen.

The **AHRS** frame to the right of the **GPS MODE** frame contains a button. If this button is clicked, the AHRS data will be recorded in the data files. The AHRS data stream adds roll, pitch, and heading. In cases where the site is very flat this may not be needed, but when there is more than gradual topographic variations, the AHRS information should be recorded. Otherwise, the inversions for target parameters may not be accurate. We recommend that the AHRS data be used in all cases.

The **RUN CONFIGURATION FILE** frame will always come up with "Last_Run" as shown in Figure 5.3. The up/down button allows the operator to toggle through all the saved configuration files. Select whichever one is desired. If changes are made to the current run configuration and it is intended to save these changes in a new configuration file, the **SAVE** button can be clicked and the configuration file directory will come up, Figure 5.5. Enter a new file name (in this case you must include the extension ".con") and click on **OK**. If the **SAVE** button does not take you to the "Run Config Files" directory, use the Windows up arrow to navigate to the desired directory. Normally, these will be located in C:\ALLTEM System Settings\Run Config Files.
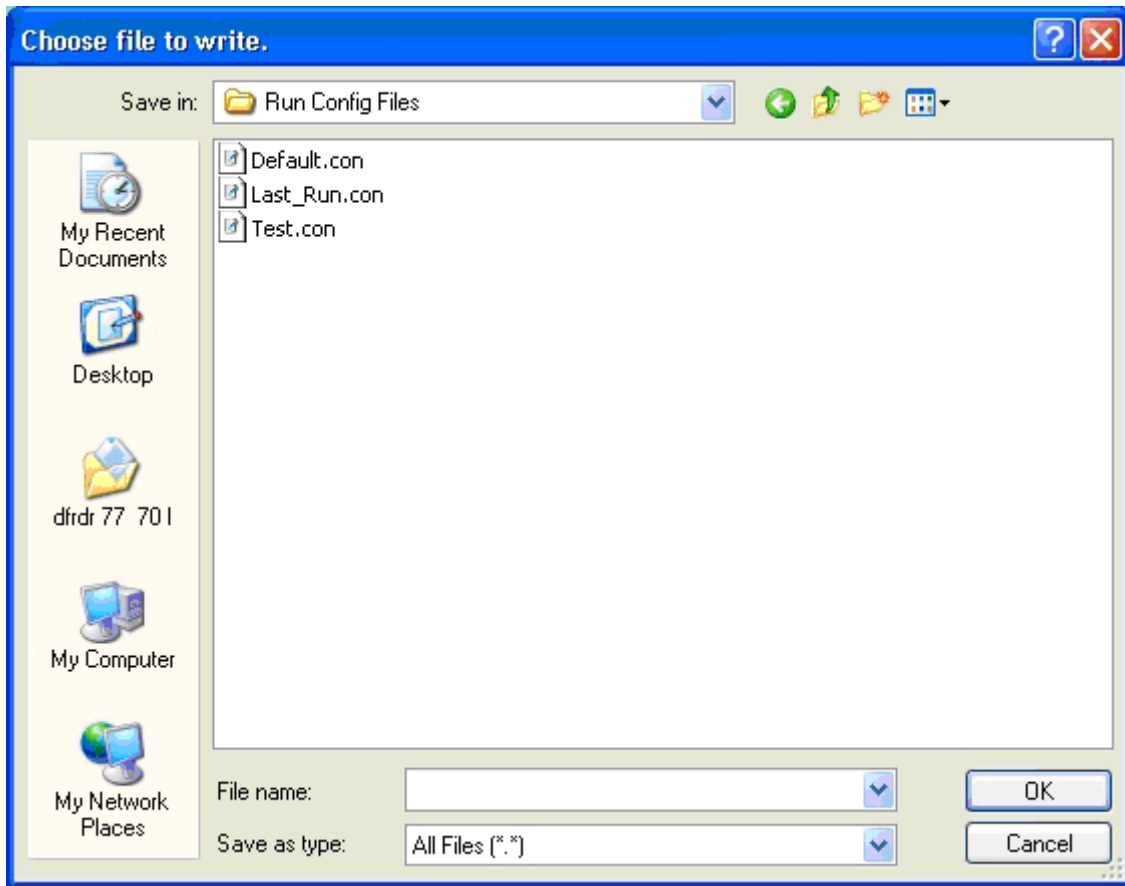
Figure 5.5. The **"Run Config Files"** directory. A new configuration file may be created by entering a new file name (with a ".con" extension) and clicking the **OK** button.

When the **ACCEPT** button (Figure 5.3) is subsequently clicked, the new configuration file will be copied into "LAST_RUN."

The **COIL AMPS (PEAK)** frame can be used to adjust the peak current. Normally this is left at the maximum (11 A) value. The power amplifier should not overheat even in high ambient temperatures, but if it does, a lower peak current can be specified. Another possible situation in which a lower current value could be chosen would be operation over very large shallow targets where RX amplifier saturation might occur.

The **COIL DRIVE MODE** frame allows the operator to choose between the normal "Sequence" mode that automatically cycles through all three TX coil polarities, and a single-axis mode of operation. If the objective is high speed detection–and-location-only operation, a single coil, most likely the Z-axis coil, could be selected. If "Single" is selected, all three coil currents in the **COIL AMPS (PEAK)** frame will be set to a value of "0." The operator must then enter the current value, typically "11", that will be used in the selected axis. It is only possible to enter current values for the selected axis. The other two axes are set to "0" and are blocked from entering non-zero values. Note that if "Single" is selected followed by "Sequence," it will be necessary to manually enter "11" for each of the three axes. Previous current values are cancelled

and not remembered when "Single" is selected, so unless the operator really intends to use only a single axis it is recommended that the "Sequence" coil drive mode not be altered. Also note that if the coil drive mode is in "Single" when the **ACCEPT** button is clicked, that setting will be placed into the "Last-Run" configuration file and when the program is initiated the next time, the system will come up in "Single" mode. It is suggested that a new directory be created for each survey area (such as CampStanleyB20 in Figure 3.4). Under that directory, create a new directory for each day of the survey (such as 23Feb11), and select that directory with the Browse icon. Then, in the **File Name** field, name the files with the same name as the date directory (i.e. 23Feb11). Try not to use the "_" delimiter in the file names, as it causes problems when the calibration files are later being processed by the Oasis data inversion program. A better choice is to use the "-" delimiter.

When all information and parameters are as desired, click the **ACCEPT** button at the upper right. An alternative that avoids the use of the touchpad is to press the **F1** button.
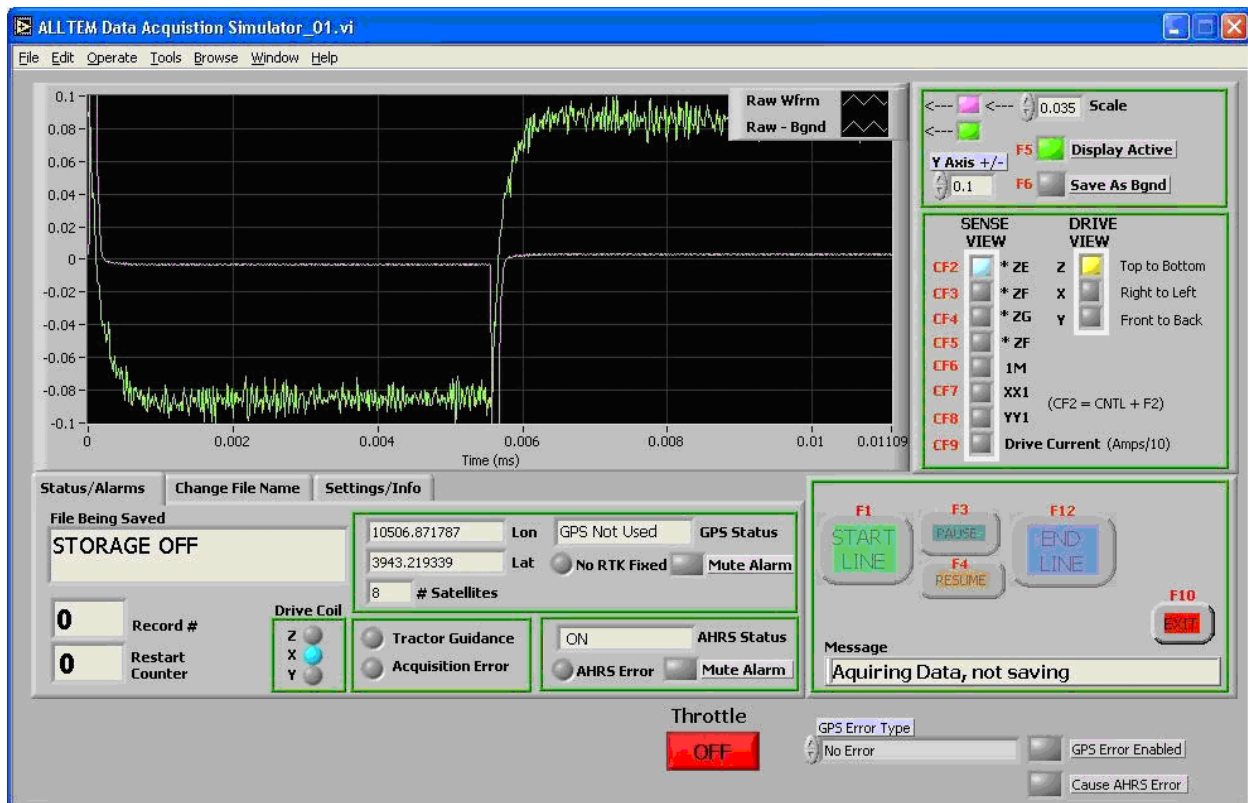
Figure 5.6. Data Acquisition panel example.

When the **ACCEPT** button is clicked, the setup screen disappears and the system data acquisition panel is restored in fully operational mode. An example is shown in Figure 5.6.

The example panel data display contains two waveforms. The pink trace is the raw data waveform, scaled by 0.035. The scale factor may be easily changed by the up/down **Scale** button to the right of the data display to keep it within the limits of the vertical axis, here shown as +/- 0.1 volts. Alternatively, the vertical, Y-axis, range can be changed with the "up/down" **Y Axis**

+/- button. The green trace is the raw data minus a background waveform, **Raw-Bgnd. Note that the green trace appears only after the Save as Bgnd button (discussed below) is clicked.** There are two additional buttons in this frame. The **Display Active** button shown in this example is illuminated, indicating that the display is active. This is the normal mode of operation and it can be very useful to see when the system has passed over a target. This display can also visually flag system malfunctions. The operator can shut off the display if the data display is visually distracting. Another rare circumstance might be when the **Restart Counter** under the **Status/Alarms** tab, discussed below, begins to count multiple times. This usually indicates that some system operation is taking longer than usual. **Note that these comments relative to the Restart Counter and system are pertinent only when running the actual ALLTEM system. Conditions that could cause the Restart Counter to count are not simulated.** Shutting down the graphics data display makes extra time available in each data cycle and might alleviate the difficulty, though the tradeoff here is the lack of an immediate visual cue that something in the data acquisition is amiss. Especially if the **Restart Counter** continues to count, it would be advisable to occasionally toggle the **Display Active** button to check whether the data are unreasonable, indicating that something in the system needs attention. The **Display Active** button can be toggled using the **F5** function key and this is the preferred way to do this as moving a cursor with the touchpad and clicking takes more system time than pressing the **F5** function key.

The other button is **Save As Bgnd**. This button, when clicked, saves the current raw data waveform and subtracts that waveform from all subsequent waveforms. The button illuminates briefly while the background waveform is being stored. **Background subtraction only affects the display. The data written to disk are not altered.** During data collection it is recommended that this button be clicked at the beginning of data acquisition when the system is deemed to be not over a target. When this is done, the green trace is much more sensitive to deviations from the stored background waveform. As the system drifts, it helps to repeat this from time-to-time, when the system is deemed to be not over a target. These repetitions reset the background to a more recently acquired waveform, thus compensating for normal system drift. The green trace, when the system is not over a target and the **Save As Bgnd** button has been recently clicked, would ideally be a flat line. There will always be some noise, of course, and some system drift as well. System drift will produce a square wave, with spikes at the transitions, that grows in amplitude over time. This square wave drift can again be reduced in amplitude by a repeated use of the **Save As Bgnd** button in the manner described above. The **F6** function key performs the **Save As Bgnd** and use of the function key is the preferred method of doing this operation for the reason explained in the previous paragraph.

In the example shown, the system is over a target, as is evident from the curved green waveform. The noise observed in the displayed waveform in this particular example is about +/- 20 mV maximum. Noise can vary considerably depending both on local electromagnetic interference levels and what particular TX-RX coils are activated and displayed, and also based on what filter settings are used (see the ALLTEM system operator's manual). Substantial further noise reduction is accomplished during data processing.

In the **SENSE VIEW** and **DRIVE VIEW** frame, just below the display control frame, the **ZE (SENSE VIEW)** and **Z (DRIVE VIEW)** buttons are illuminated, indicating that the display is

showing the data for the case that the vertical Z-axis (physically horizontal) TX coil is being driven and the data from the top and bottom diagonally opposite ZE RX coil pair are being displayed. The bottom button in the **SENSE VIEW** column will display the waveform current (Amps), divided by 10, for whichever drive coil is selected and can be used to check that the currents driving each TX coil in sequence are the expected triangle wave of the correct amplitude. Excluding this bottom button, there are 7 choices for RX coils and 3 for the drive coils. Nineteen of the possible 21 combinations are meaningful and recorded. The **XX1** sense is not meaningful when the drive coil is **Y** and the **YY1** sense is not meaningful when the **X** drive coil is selected. Waveforms will appear for these cases, if selected, but they will likely be saturated and are not recorded in any event. In order to select a particular RX coil pair in the **SENSE VIEW** column either move the cursor with the touchpad or mouse over the desired button and click, or use combination of the Control key + Function Key as shown on the pane in red characters. The drive coil selection must be done using the cursor and click method.

In the example shown in Figure 5.6 the **Status/Alarms** tab is selected. Under this tab a number of pieces of information and alarm indicators are shown. Since there are no files being saved in Figure 5.6, the **File Being Saved** filed indicates "STORAGE OFF". If file saving had been chosen in the setup screen, the **File Being Saved** field would contain the filename currently being saved, such as "Test2_0.***" in Figure 3.6. (See the discussion for Figure 3.6 for a description of the behavior of the **File Being Saved, Record #**, and **Restart Counter** fields when file saving is enabled.)

This paragraph describes conditions that are not simulated, but is included for completeness. The **Restart Counter** ideally should remain at zero. A non-zero value indicates that the digital-to-analog (D/A) output signal sent to the TX coil current amplifier has lost synchronization with the analog-to-digital (A/D) board that samples the signals from the RX coils. This condition would cause anomalies in the data and might cause switching relay damage as well because the electromechanical relays that switch between the three TX coils should only be switched at a point where there is no current flowing in the energized TX coil. If the relays are switched when significant current is flowing, high voltages will be produced at the relay contacts causing arcing as the contacts open. If this happens repeatedly the contacts can become burned and pitted, causing their contact resistance to increase to an unacceptable level. The synchronization between the A/D and D/A boards is constantly monitored in software. Should synchronization be lost, the system is automatically stopped and restarted to recover synchronization. This happens without operator intervention, but it may take up to 1 second, so substantial gaps in the data along a line can occur. This counter should be watched, especially near the beginning and at the end of lines. An audio alarm for restarts that beeps several times has also been implemented, in addition to the audio alarms for loss of GPS-RTK and AHRS data errors. The **Restart Counter** audio alarm cannot be muted. A restart condition can occur just after the **START LINE** or **END LINE** buttons have been clicked. In these cases the system is probably not yet moving or is outside the planned survey area, so there is no serious consequence. Occasionally this can happen when the GPS looses RTK-FX or serial communications with the GPS or AHRS fail in some fashion. It is also possible for the Windows OS to initiate a background service request that slows the cycle time. Because the cursor and click method generates service interrupts, the function keys should be used as much as possible

to initiate actions. **Should the Restart Counter increment repeatedly, something is amiss and data collection should be suspended until the cause is determined and corrected**.

The **Drive Coil** frame, to the right of the **Record #** and **Restart Counter** fields, illuminates a button to show which of the three (X, Y, or Z) TX coils is currently activated. This display is automatically controlled by the system.

To the right of the **File Being Saved** field is a GPS frame that contains four indicators and two buttons. In the left column are longitude, **Lon**; latitude, **Lat**; and number of satellites, **# Satellites.** The longitude and latitude numbers are strings that come over the serial port from the GPS. They indicate the location of the rover GPS antenna on the ALLTEM cart. When the cart is in motion these numbers should be progressively changing. In this simulator there is a **Throttle** button to simulate cart motion. When the **Throttle** button, middle bottom in Figure 5.6, is green and says "**ON**" the **Lon** and **Lat** numbers will increment. When the **Throttle** button is red and reads "**OFF**", the **Lon** and **Lat** numbers will cycle back and forth between the last two values used in the replayed data stream. The **# Satellites** field shows the number of satellites the GPS system is using to calculate positions. This is one factor determining the precision of the calculated positions. See your GPS manual for more information regarding position error bounds. In the second column there is a field labeled **GPS Status.** In this example the field reads "RTK_FX" indicating that the GPS is reporting that it is operating in the Real-Time Kinematic Mode and has achieved a lock on the phase information from the various satellites. This is indicated by the "FX" portion (meaning fixed solution) of the displayed string. Directly under this field is a button that will illuminate when any condition other than "RTK_FX" exists. **Note that "RTK_FX" is the only GPS condition that is expected to produce the accuracy necessary for target classification.** Modeling has shown that positions with errors no more than +/- 5 cm are needed for confident inversion/classification results (other data conditions are also relevant here, but discussed elsewhere). When the GPS loses "RTK_FX", an audio alarm sounds, as well as illuminating the button. If the audio alarms are not desired they can be muted by clicking the **Mute Alarm** button. In this simulator there are options for simulating various errors for the GPS and AHRS data. Simulated errors can be selected by clicking on either or both of the buttons to the far right of the **Throttle** button. The top of these two buttons is labeled **GPS Error Enabled**. When this button is illuminated, the type of GPS error can be selected by using the smaller up/down button just to the left. The **Cause AHRS Error** button has no options. Activating these buttons will cause responses in the **GPS Status** and **AHRS Status** discussed below.

Under the GPS frame are two smaller frames. On the left is a frame with a button labeled Acquisition Error. This button will illuminate if either there was a non-zero current at the time the drive coils were switching, or the data acquisition loop took more than 20 ms past the normal time that the A/D waveform buffers should have been read during the data acquisition loop. The Tractor Guidance button indicates whether the Tractor Guidance button was selected in the setup screen, Figure 5.3.

Moving to the right is the AHRS information frame. There is one field, **AHRS Status**. This field says, "ON" to indicate that AHRS data are being recorded because the operator clicked the **AHRS** button in the setup screen (Figure 5.3). We recommend that AHRS data be recorded for

all surveys. When AHRS data are not being recorded, the buttons in this frame are not active. However, when AHRS data are being recorded there are two additional buttons in this frame that are active. The **AHRS Error** button will illuminate if an AHRS data error were to occur and an audio alarm would sound. The **Mute Alarm** button, when clicked, mutes the audio alarm. This program permits simulation of these conditions.

The next frame on the right contains five buttons and a message field. The buttons are: **START LINE** (F1), **PAUSE** (F3), **RESUME** (F4), **END LINE** (F12), and **EXIT** (F10). Although these buttons can be selected by moving the cursor and clicking, it is more efficient to use the indicated function keys, F1, F3, F4, F12 and F10. Note that the grayed-out buttons are not available, because they do not make sense under the circumstances. For example, in the case of Figure 5.6, the file storage had not been enabled in the setup screen, so none of these buttons are available. If file storage had been enabled, the **START LINE** button would have been available. *In that case*, once **START LINE** has been clicked, **PAUSE** can be selected if it is necessary to stop for some reason while on a line. **PAUSE** only suspends the saving of waveforms. When ready to proceed, the **RESUME** button can be clicked, and saving will restart. The message field shows "Press Start Line to start saving..". To protect against the possibility of assuming that data are being saved when they are not, the **START LINE** button cannot be activated in this screen unless the **Write to Disk** button in the **DATA FILE STORAGE** frame in the **SETUP** screen (Figure 5.3) above, was checked. Nevertheless, it is good practice to read the message field just after the **START LINE** button has been clicked. **There is no protection against failure to press the START LINE button!** After **END LINE** has been clicked the **EXIT** button is available. This button should be used to exit the program because it allows the program to shut down gracefully and guarantees that the current to the drive coil has been set to zero. When the **EXIT** button is pressed the program exits and brings up the initial front panel (Figure 5.2) again. At this point the operator can either restart the program by clicking the run arrow icon on the menu bar, or close the program using the Windows "X" button.

When the **Change File Name** tab is selected (Figure 5.7) the operator is given the option of changing the file name into which data are being stored. The only normal use of this option is for taking calibration data where it is desirable to keep the TX coils active without any interruptions, but necessary to rename data files to correspond to the calibration ball locations.

Figure 5.7. The **Change File Name** tab, lower left of screen, allows the operator to choose another file name for storing subsequent data.

To protect against accidental file name changes, two buttons must be clicked to implement a change. First click on the **Allow FileName Change** button, then enter the desired new file name, without extension, If a revised line number is desired, enter the number in the **Change Line#** field. Then click on the **Change Name** button to implement the file and line # changes. This action will cause both buttons to revert to their non-illuminated state, ready for another file name change. To the right of the field is a comment, "Select both buttons to accept new filename."

A GPS error condition is shown in Figure 5.8. First note that in the **"File Being Saved"** field in the **Status/Alarms** tab the message "**STORAGE OFF**" appears. This condition is also flagged in the **Message** field at the bottom of the **START LINE – END LINE** frame, which reads "**Acquiring Data, not saving**" The background will flash red and white to catch the operator's eye. This condition can be simulated by not checking (or unchecking) the **Write to Disk** button (Figure 5.3). The **GPS Error Enabled** button is illuminated, so GPS error is being simulated. This is reflected by the fact that the **No RTK Fixed** button is illuminated in the GPS frame. The **Mute Alarm** button next to the **No RTK Fixed** button may be toggled and the audio alarm will be made audible or suppressed. The type of GPS error simulated in this example is **"Non-RTK mode."** This error is noted in the **GPS Status** field as "DIFFER," indicating that a differential GPS mode is simulated. The **Throttle** button is red and reads **"OFF,"** simulating a condition in which the tractor is not moving along the survey line. Alarms and mute functions can be simulated for the AHRS system by clicking the **Cause AHRS Error** button.
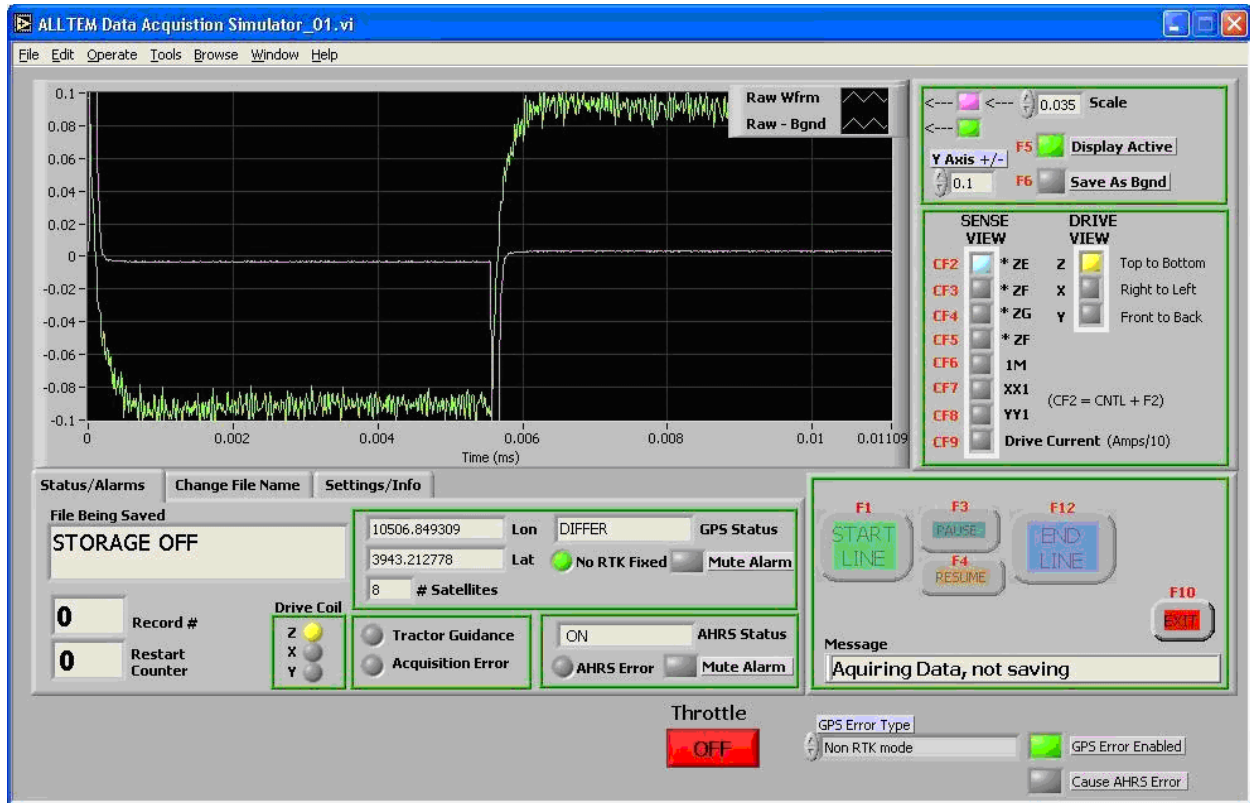
Figure 5.8. **GPS ALARM simulation** with a GPS error condition shown.
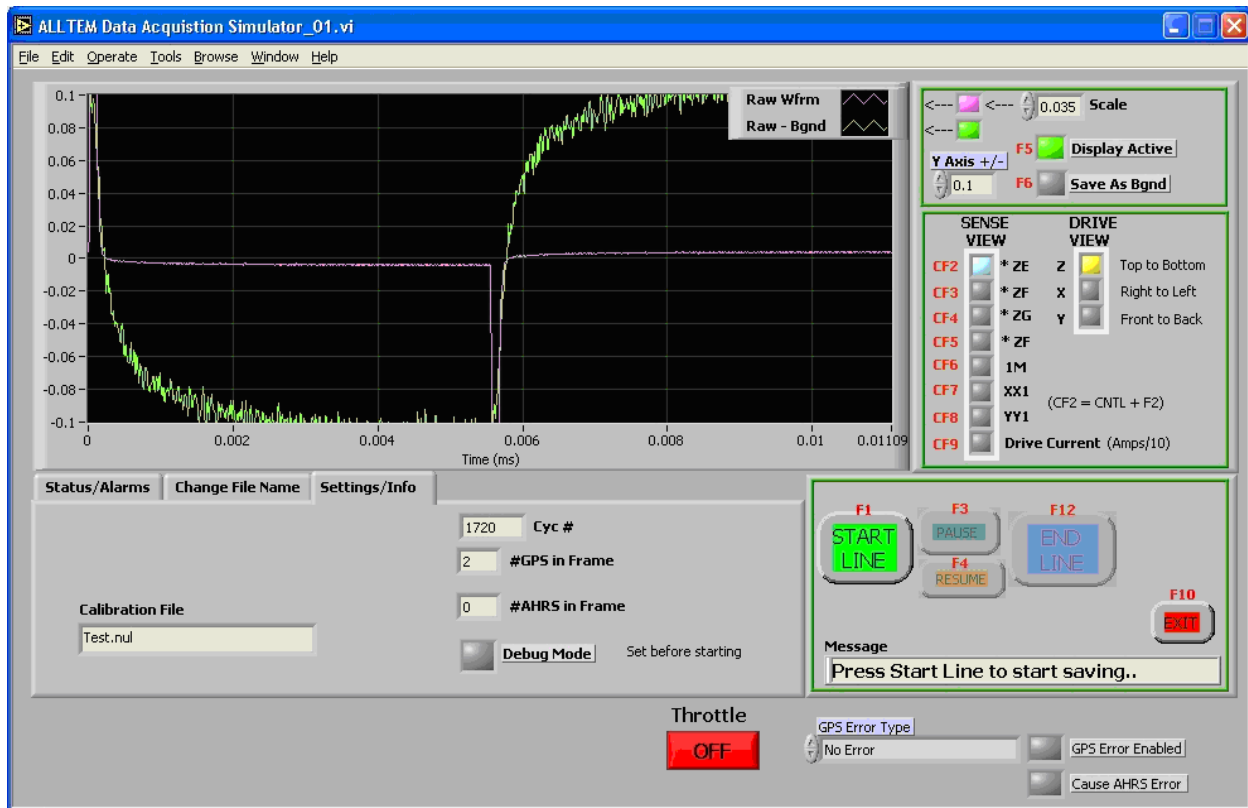
Figure 5.9. This **Settings/Info** tab screen brings up four fields and a **Debug Mode** button.

The **Settings/Info** tab brings up a screen that includes a **Debug Mode** button, as shown in Figure 5.9. This screen contains information and buttons previously described, but also includes the fields **Calibration File**, **Cyc #**, **#GPS in Frame**, and **#AHRS in Frame** and the **Debug Mode** button. The **Cyc #** field shows the number of data cycles that have been completed since the program was started. This number will be reset to zero and count up from zero every time the program is restarted by the operator, as well as every time the program automatically resynchronizes (see discussion of the **Restart Counter** above. The **#GPS in Frame** field indicates how many GPS readings are included within one time-frame, is 66 ms long and corresponds to the amount of time required for data acquisition for one polarity of the TX (33ms dead band for relay switching + 33 ms of waveforms). When the GPS is being used this is usually "1", but may be "2" because the GPS updates position information every 50 ms and is asynchronous to the ALLTEM 66 ms data frame. In the example we show, the AHRS was not used, so the field showing the number of AHRS readings shows "0". When the AHRS is being used the number will usually be "2" because the AHRS updates data at an approximate 30 ms interval.

The **Debug Mode** may slow the system and should not normally be used. If it is used, the **Debug Mode** button should be set before starting. It brings up additional information which is of use only during debugging by a system expert and will therefore not be further discussed here. Contact the USGS ALLTEM system engineer if debugging help is needed.

6.0   DATA PREPROCESSING PROGRAM

6.1   Purpose

The data preprocessing program takes the raw ALLTEM data and performs necessary operations to convert the data into the form needed by the inversion/classification software. If desired, entire processed waveforms can also be saved for analysis by other methods as discussed below in Section 6.3.1, Step 3.

6.2   Conditions for Use and Comments on Handling Incomplete or Defective Data

In addition to installation of this program, certain files must be placed as shown below and raw data files to be processed must be available to the program. These will be discussed in the appropriate following sections.

If there are missing line numbers in the data set, this may be determined by visually examining the sequence of data file names. The preprocessing program moves through the data files sequentially and will stop when it cannot find the next number in the sequence. However, there is a provision to enter missing line numbers so that these will be skipped. We discuss how to do this in section 6.3.1, step 4 below.

If a data set is complete and free of all defects the data preprocessing can be done automatically in a single pass. However, large data sets typically contain anomalies, so the more common case will involve more than one pass through the data by this preprocessing program. Prior to preprocessing it may be known from field notes or other information that a given data set has anomalies and what those anomalies are. If a data set contains unknown anomalies, the first pass through the data set with this preprocessing program can find and identify these anomalies and a second pass through the preprocessing program will then be necessary. Much of the following discussion deals with how to handle various kinds of defects in the data set and therefore assumes that the data set being processed has already been through the preprocessor once to find needed information about anomalies in the data. In a subsequent pass the preprocessor uses information about anomalous portions of the data and makes some "repairs" so that the data may be satisfactorily preprocessed. For example, there is a provision to repair short-term loss of "RTK_FX" status in a data set. When the following discussion mentions information about the data that, in general, would not be known, that information would be obtained either from a first pass through this preprocessing program or, in the case of repairing position data, from an outside program. These situations are discussed in the following sections.

6.3   Operation

To launch the program, double click on the icon "Shortcut to ALLTEM Data Preporcessor_01" as shown in Figure 6.1.

Figure 6.1. ALLTEM Data Preprocessor icon.

The startup screen should look like the example shown in Figure 6.2. If the program comes up with another tab active, change to this one by clicking on the **Common Controls** tab.
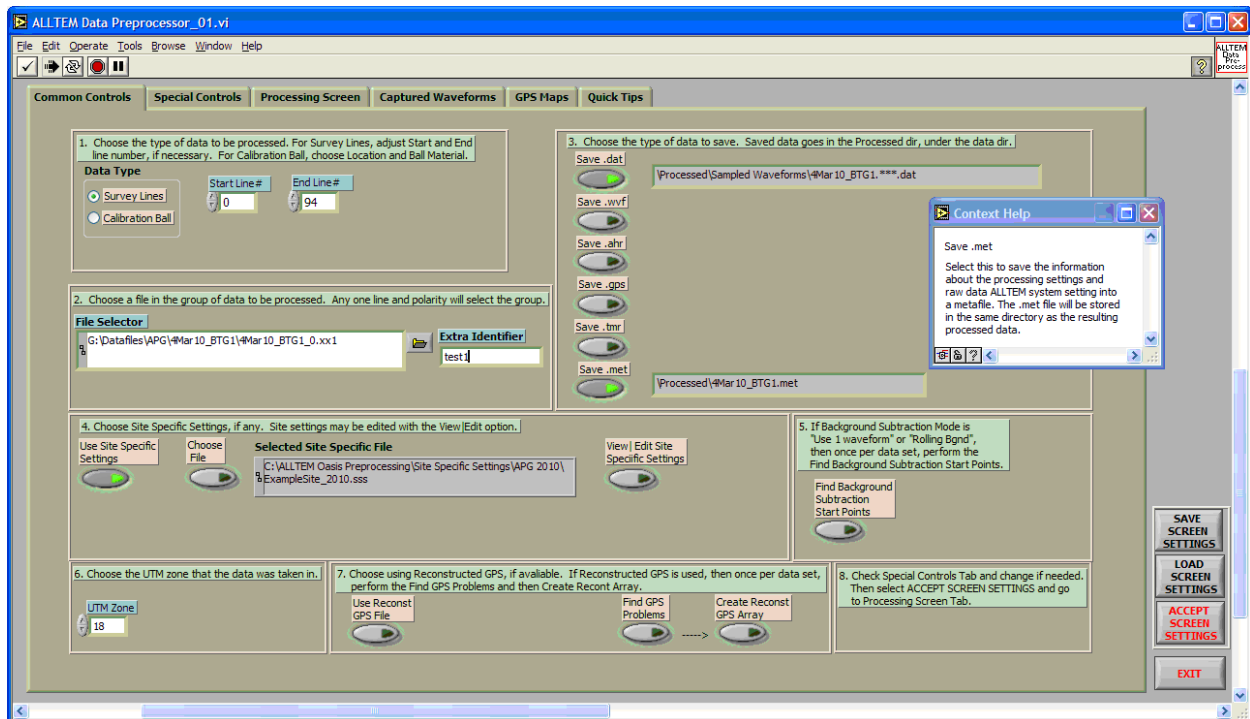
Figure 6.2. The Common Controls screen showing the ALLTEM Data Preprocessor program screen.

6.3.1   Common Controls – Survey Lines Case

Next click the run arrow icon in the menu bar at the upper left. This and other buttons were already clicked to get the example screen shown in Figure 6.2. A context-sensitive help window is active on the right. We describe actions to be taken in the order of the tabs and the numbered frames brought up under each tab. Context-sensitive help can be toggled on and off using Ctrl-H or by using the "Help" pull-down menu. The values displayed in various fields are read from a screen settings file (described later). The program remembers the last-used screen settings. If a different previously saved screen settings file is to be used, click on the **LOAD SCREEN SETTINGS** button at far lower right.

Step 1.   Choose the type of data to be processed

In this frame are two radio button selectors for choosing the type of data to be processed. We will here consider only the **Survey Lines** data type. The **Calibration Ball** data type will be considered in a later sub-section. Each set of raw data will have a set number of lines with assigned line numbers, so it will be necessary to enter the corresponding line numbers to be processed. Enter the desired beginning and ending line numbers in the **Start Line #** and **End Line #** fields for the data set to be processed. The numbers may be entered using the up/down buttons or may be typed in. A subset of the lines may be selected for processing, but of course it makes no sense to ask for line numbers less than or greater than those that exist in the selected data set. The case where some lines are missing within a data set is considered below.

Step 2   Choose a file in the data set to be processed

In the **File Selector** field a data file, including the file path, is shown. To choose a different file, click on the browse icon. A window will open as shown in Figure 6.3. Select any file from the set and the entire set will be selected for processing. The ordinary Windows options for navigation to another folder are available. Click **Save** and the selected file will be entered in the file selector field.
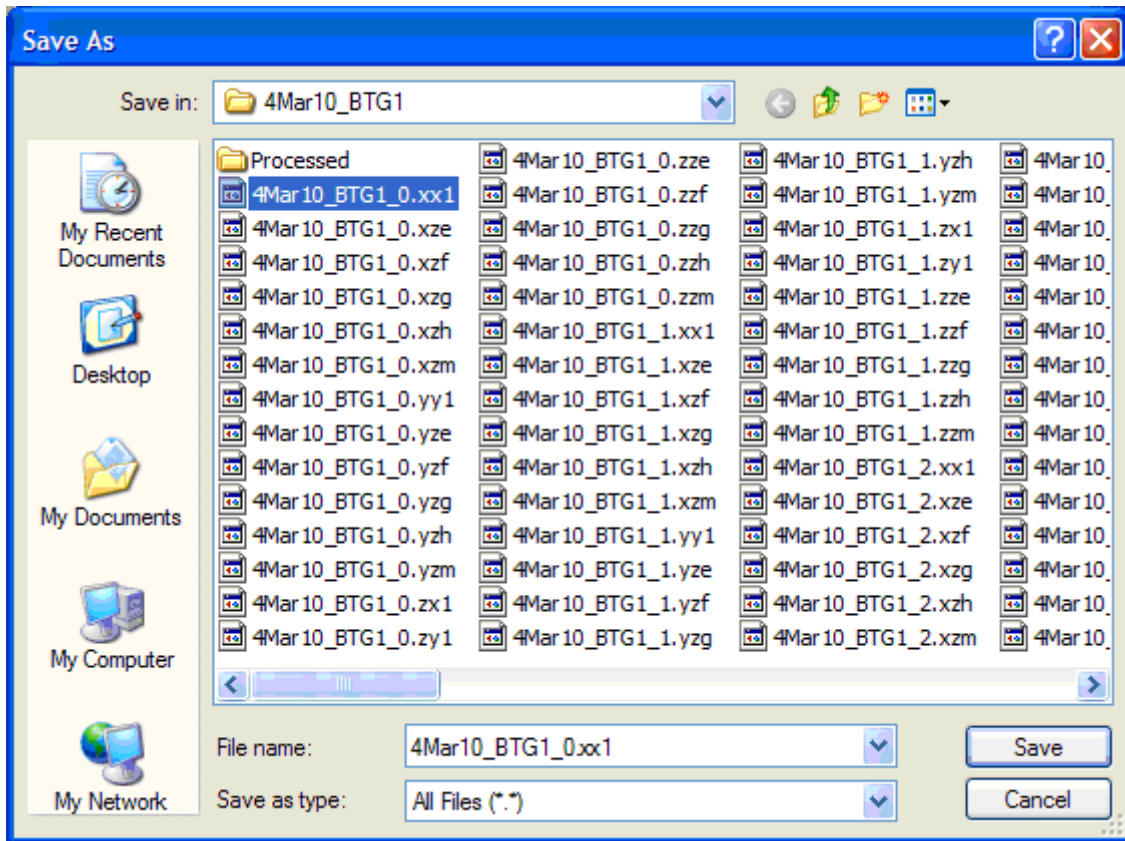
Figure 6.3. Example of files listed in the selected data directory.

An **Extra Identifier (**Figure 6.2) can be entered to uniquely identify the processed data files. A Preview of the resulting file names can be seen in the file name fields shown in frame 3 to the right of frames 1 and 2.

Step 3   Choose the type of data to save

In this frame there is a column of six selector buttons that will control the type of data to be saved. If the intention is to process the data using the USGS target inversion/classification software that runs under Geosoft Oasis montaj, the top button, **Save.dat** should be selected. The saved data will include a series of time samples from each waveform and will be stored in the indicated destination folder as a spreadsheet with a ".dat" extension. A separate spreadsheet is produced for each of the selected polarities (default number is 19). Each spreadsheet has columns containing line number, record number, northing and easting in meters, a percentage value for non-ferrous peak, voltage values at each of 15 sample numbers, and the value of a millisecond timer. The northing and easting values are converted by the program from the latitude and longitude values obtained from the GPS unit during the survey. These spreadsheets can be imported by Surfer (Golden Software), Excel (Microsoft) and Oasis montaj (Geosoft), among others.

The second button, **Save.wvf**, will save a processed version of the entire waveform. This may be desirable for other types of data analyses, but has the disadvantage of creating large data files. In Figure 6.2 this is not selected

The following three buttons, **Save.ahr**, **Save.gps**, and **Save.tmr** are used for AHRS data. If AHRS data are not going to be used for analysis, inversion or classification processing, these three types of data need not be saved. In Figure 6.2 these are not selected. If saved, the contents are ASCII data and can be read with a text editor, such as WordPad or Notepad in Windows, for example. As of the writing of this manual the AHRS data have not been included in the target detection/inversion/classification process.

The final button, **Save.met**, saves a metafile containing information about the processing settings and ALLTEM system settings from the raw data. The metafiles are saved in ASCII format in the same directory as the processed data. It is recommended that these metafiles be saved.

Step 4.   Choose Site Specific Settings

Site specific settings contain information needed to process data from a particular site. Initially, as part of the installation, a default (empty) site specific file should have been created in a subdirectory under the directory "C:\ALLTEM Oasis Preprocessing\Site Specific Settings". When the **Use Site Specific Settings** button is illuminated and the **Choose File** button is pressed, a screen similar to that in Figure 6.4 appears.
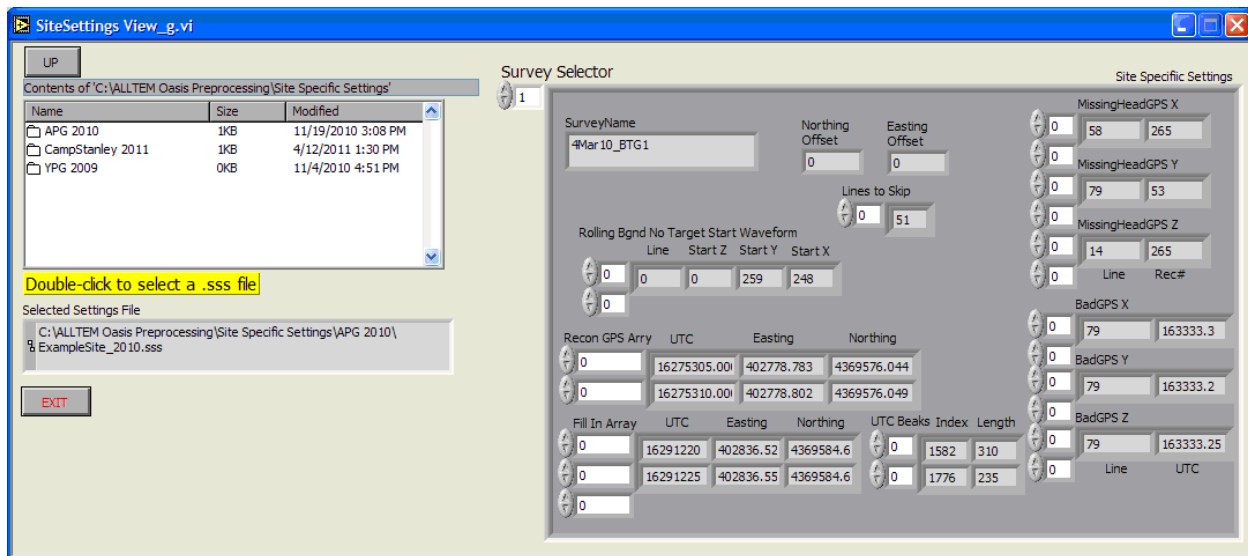
Figure 6.4. An example of the **Site Specific Settings** dialog window.

In the example shown in Figure 6.4 the last-used file is shown in the **Selected Settings File** field. To access a different file, locate and double-click on the desired file and the contents of the **Selected Settings File** field will change to the selected file. Some of the settings contained in this file are shown on the panel to the right. **Note that if anything needs to be edited and saved this is _not_ the place to do it.**

To edit, after the desired Site Specific Settings file has been chosen, click the EXIT button. The window shown in Figure 6.4 will close. Then click the **View/Edit Site Specific Settings** button to bring up the panel by itself, as shown in Figure 6.5. This is the place to edit and save edited settings to a Site Specific Settings (".sss") file. Note that the fields within the red frames are for information only and are not intended to be edited. These fields are automatically filled in when the Find GPS Problems and/or Create Reconst GPS Array options are used. If something inside these fields is changed inadvertently, click on the Windows "X" at the upper right corner to close the screen without saving.

Figure 6.5. View/Edit **Site Specific Settings** screen.

Use the up/down **Survey Selector** button, at the upper left, to choose the particular data set to be processed. In this example the **Survey Selector** shows a "1." Depending on the site, there may be several data sets to be processed from a given site or part of a site. These sets are identified by name in the form "DMmmYY_SurveyName" (for example 4Feb11_BTG1, or 23Mar09_Test). The survey names should be unique, but repeat surveys of the same site, on the same day might take the form "4Feb11_BTG1Survey2", "4Feb11_BTG1Survey3," and so forth.

The **Northing Offset** and **Easting Offset** will both normally be "0", but are included for those cases in which GPS positions are known to be off due to possible errors in the GPS base station's exact location. This could happen if the base station's location was derived from using the "Get Here" technique, versus placing the base station over a surveyed benchmark and using the benchmark coordinates. Using a software program provided by the GPS manufacturer (Leica), the error due to using "Get Here" can be calculated and placed in the Northing Offset and Easting Offset fields. The offsets shift the ALLTEM location data being processed to the corrected values.

Just below the **Easting Offset** field are two fields and two corresponding up/down buttons. In the first field is an index number. The field to the right has a label **Lines to Skip**. In this example the first line to skip, index 0, is line 51. This is because in the particular data set used for this example, line number 51 is missing from the data. Any lines to be excluded from the processing, whether missing or with uncorrectable problems, can be entered here and will be remembered when the **Save** or **Save As** buttons are subsequently clicked. The present implementation of this processing software will stop and give an error message that a file cannot be found, if a line is missing and not called out in the **Lines to Skip** field.

At the right side of the panel is a column of 12 up/down buttons adjacent to six fields with labels for missing or bad GPS in the X, Y, or Z positions. This information will exist only after the data have been processed with the **Find GPS Problems** button selected, as discussed below in Step 7. In a perfect dataset these fields would be empty, but typically there are some GPS errors. To examine these, use the up/down buttons. The top button in each pair moves the view up or down through rows of data. Each row of data contains a line number and a data point within that line. The bottom button of the pair scrolls through the columns. **Bad or missing GPS locations are integral to the data – the user should not edit anything in these data fields.** If there are only a few errors or bad GPS values and these are not sequential, the consequence should be minimal. During processing, records with missing or bad GPS values will be skipped. A few scattered missing data records should not significantly degrade target detection/classification performance. If, however, there are many missing or bad GPS values and these are sequential, that is, considerable portions of a line or lines do not have good GPS data, those lines should probably be added to the **Lines to Skip** unless reconstructed GPS positions (discussed below) can be substituted.

Moving back to the left part of the panel there are the words, **Rolling Bgnd No Target Start Waveform**. Under these words are fields **Line**, **Start Z**, **Start Y** and **Start X** and buttons associated with these fields. The words **Rolling Bgnd** mean that the rolling background removal processing option has been selected. This is a method for removing system drift. The words **No Target** mean that background removal baselines must be acquired where there are no targets in the vicinity of the TX/RX coils. An algorithm finds the best of all the no-target locations along each line to use for an initial background. The words **Start Waveform** refer to the record on the survey line where the algorithm found the best waveform to use for the first-pass background removal that is subsequently applied to every point on the line. Note that the best location will not, in general, be the same for the X-, Y-, and Z-polarities. If the rolling background removal option is selected, a second pass through the data during processing will use another criterion to find additional no target locations and calculate and subtract a series of new backgrounds along

each line. There is another case where the values stored in the **Rolling Bgnd No Target Start Waveform** array are used. That is when the background subtraction mode is selected **Use 1 waveform** using .sss Bgnd file Start values (Figure 6.12). This case may be needed if the lines being surveyed are seldom over areas where there are no metallic objects under the ALLTEM cube. The data may have to be looked at on a line by line basis to find the best "quiet" area to choose a background waveform from. The manually chosen waveforms can then be stored into the **Rolling Bgnd No Target Start Waveform** array, and then used, without the "rolling background" mode being selected.

The fields **Line**, **Start Z**, **Start Y**, and **Start X** are editable, but should only be edited if it appears that the algorithm has not made a good choice for the starting points for the X-, Y-, or Z-polarities. The starting points for each line can be viewed using the adjacent up/down button. A location that is a good choice would have a waveform that, after an initial transient, has a flat baseline and low noise. The waveforms can be viewed in the subsequent processing screen. It should be noted, that if there are lines to be skipped in the **Lines To Skip** array, that there should be entries in the **Rolling Bgnd**, **No Target Start Waveform** array. For instance if lines 51-55 are missing in the survey, there should be entries in array lines 51-55 in the **Lines To Skip** array, even though there is no line data for these lines. This will keep the array indexing correct for functions that use the **Lines To Skip** array.

Below the **Line**, **Start Z**, **Start Y**, and **Start X** fields is a red-outlined frame that says "**Do not edit items in RED boxes.**" These fields have to do with reconstructed GPS data. Two conditions require the use of a reconstructed GPS file:

Condition 1: If, for some reason data from the rover GPS unit is missing, then the headers of the associated waveforms will have no valid GPS data: UTC, latitudes or longitudes. Waveform headers must be searched for missing GPS data using the Find Bad GPS procedure (discussed in detail below). The result of this procedure is a list of line numbers and waveform record numbers that have defective GPS data. This list constitutes the MissingHeadGPS arrays in the Site Specific Settings configuration file (".sss"). Furthermore, the GPS millisecond timer and record numbers are given interpolated values and the GPS mode number is set to "0", meaning non-RTK. This information is used to fill in the UTC values with interpolated UTC values in the header gaps during subsequent waveform processing. Except for short gaps in the data, interpolated UTC values and resulting position estimates will not be accurate enough for good target classification.

Condition 2: Occasionally, the rover GPS will drop out of RTK_FX mode. This can occur if the constellation of satellites prevents a RTK-fixed solution, or if there is a problem with the radio telemetry between the GPS base station and the rover GPS. Positions recorded while in a lesser mode are considered to lack the precision necessary for accurate target classification. In this case the information stored in the BadGPS arrays in the Site Specific Setting configuration file (".sss") is used. The BadGPS array contains the lines that have non-RTK GPS values. When one of these lines is being processed, a comparison search is made between the UTCs in the reconstructed GPS array and the UTCs in the array having the waveform header information.

When a match is found, the GPS Northing and Easting in the reconstructed GPS array is substituted for the corresponding values in the array having the waveform header information. This GPS information is then stored in the ".dat" or ".wfm" files. In practice, any GPS dataset containing non-RTK data is run through a computer program provided by the GPS manufacturer (Leica) that corrects these deficiencies and, in many or most cases, estimates positions that are as accurate as would have been obtained in RTK_FX mode.

Of the two conditions mentioned above, the missing data condition is far more serious. Unless data gaps are very short, interpolated positions may not be accurate enough to obtain good target inversion/classification results. Therefore, if GPS failures are observed then it is vitally important to find and eliminate the source of the GPS problem and repeat any lines that were affected.

The data fields within the red frame on the left show information in reconstructed GPS arrays **Recon GPS Array**, the **UTC, Easting, and Northing**. The **Fill-In Array** and associated fields show the arrays that are spliced in to produce the reconstructed GPS arrays. The substitutions occur at places where there are **UTC Breaks.** The associated **Index** and **Length** fields show where the breaks occurred and how many sequential data locations were affected by each break. These are information fields only, and should not be edited. The UTC Breaks are calculated by the program when the Find GPS Problems function is run.

When all of the Site Specific Settings are as desired, click the **Save** button which will cause the settings to be saved in the existing file, shown in the **Selected Site Specific File** field. Alternatively, a new Site Specific Settings file can be saved by clicking the **Save As** button, bringing up the window shown in Figure 6.6 that allows you to name a new file. Click on CREATE to create it or CANCEL to cancel.
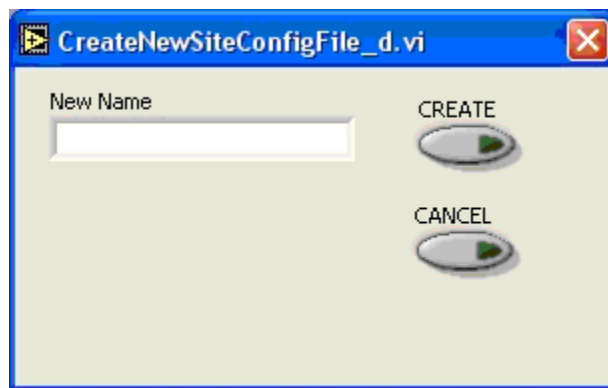
Figure 6.6. Site Specific Settings file creation window.

Step 5   Find Background Subtraction Start Points

A rolling background subtraction is the preferred method of background removal. This method looks for low-noise, no-target locations along each recorded line of data and resets the background at these particular locations. This method usually provides a better result than simply subtracting the background calculated at a single location (often the beginning of each line). Especially for long lines the system nulling may drift and repeated background calculations and subtractions have been found to provide somewhat better results in subsequent data processing for target parameters and classification. Details are in Appendix 1. In order to use this method, follow the directions and click the ACCEPT button once for each data set. When the ACCEPT button is clicked, the window in Figure 6.7 will appear. Verify that the Site Specific Settings (".sss") file is the one intended. Then do steps 1, 2, 3 and 4 as shown in the Figure. Note that the program will skip any lines that the selected ".sss" file has flagged to skip. The **Slope Limit** in step 3 is the value, used in the calculation, of the allowable slope on a given waveform that will be considered to be taken over "no target" on the line. The slope is calculated between samples 31 and 513 on the waveform. The calculation doesn't look at the first 15 waveforms saved on the line, because these sometimes are taken when the system is in a "restart" condition (see discussion associated with Figure 3.6). If the start points calculated have a lot of "15s" in them, then the Slope Limit value should be increased. The Slope Limit should be decreased if the start points are ending up in areas where it is obvious there are "targets" on the survey line (from inspection of the profile and waveforms in the **Processing Screen**). A value of 0.002 volts has worked well in surveys where metal items are sparsely populated along the lines. Areas with a lot of metal along the line may not work well with the algorithm, and "quiet", non-metallic spots may have to be selected manually in the **Processing Screen**.
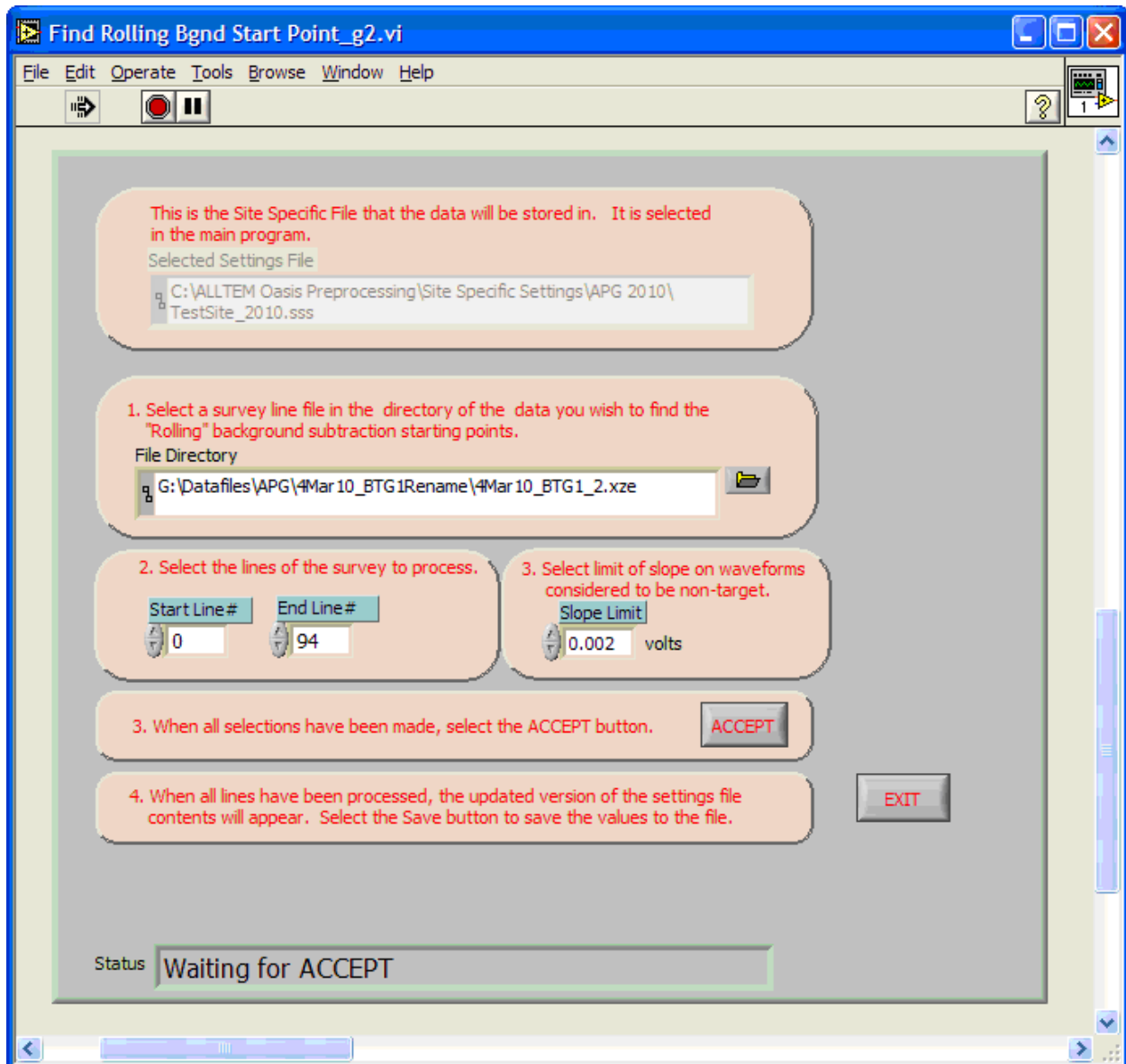
Figure 6.7. Rolling Background Start Point program window.

When the processing has completed, revised settings for the ".sss" file will appear. It will look similar to Figure 6.5 above. Be sure to click the **Save** button to save the revisions to the ".sss" file.

Step 6   UTM zone

Be sure to enter the UTM zone in which the data were taken. See, for example, *http://egsc.usgs.gov/isb/pubs/factsheets/fs07701.html* [URL]. Zone 18 is appropriate for Aberdeen Proving Ground where the example data were collected. If a wrong zone is used in processing, the positions will be incorrect and it will be necessary to reprocess the data with the correct zone number.

Step 7.   Reconstructed GPS

If the data set being processed has no missing or non-RTK_FX GPS data, then the operations described here are not needed. For the first pass through the data it will generally not be known whether or not there are bad or missing GPS data. There are two options for detecting the presence of missing or bad GPS data. One of these is to plot the position data in Geosoft Oasis montaj and inspect the lines visually for gaps or anomalous jumps. Alternatively, use this LabView software to scan the headers for missing or bad positions by first clicking the **Use Reconst GPS File button** and then clicking the **Find GPS Problems** button. When this is done a window similar to the one in Figure 6.8 will open.
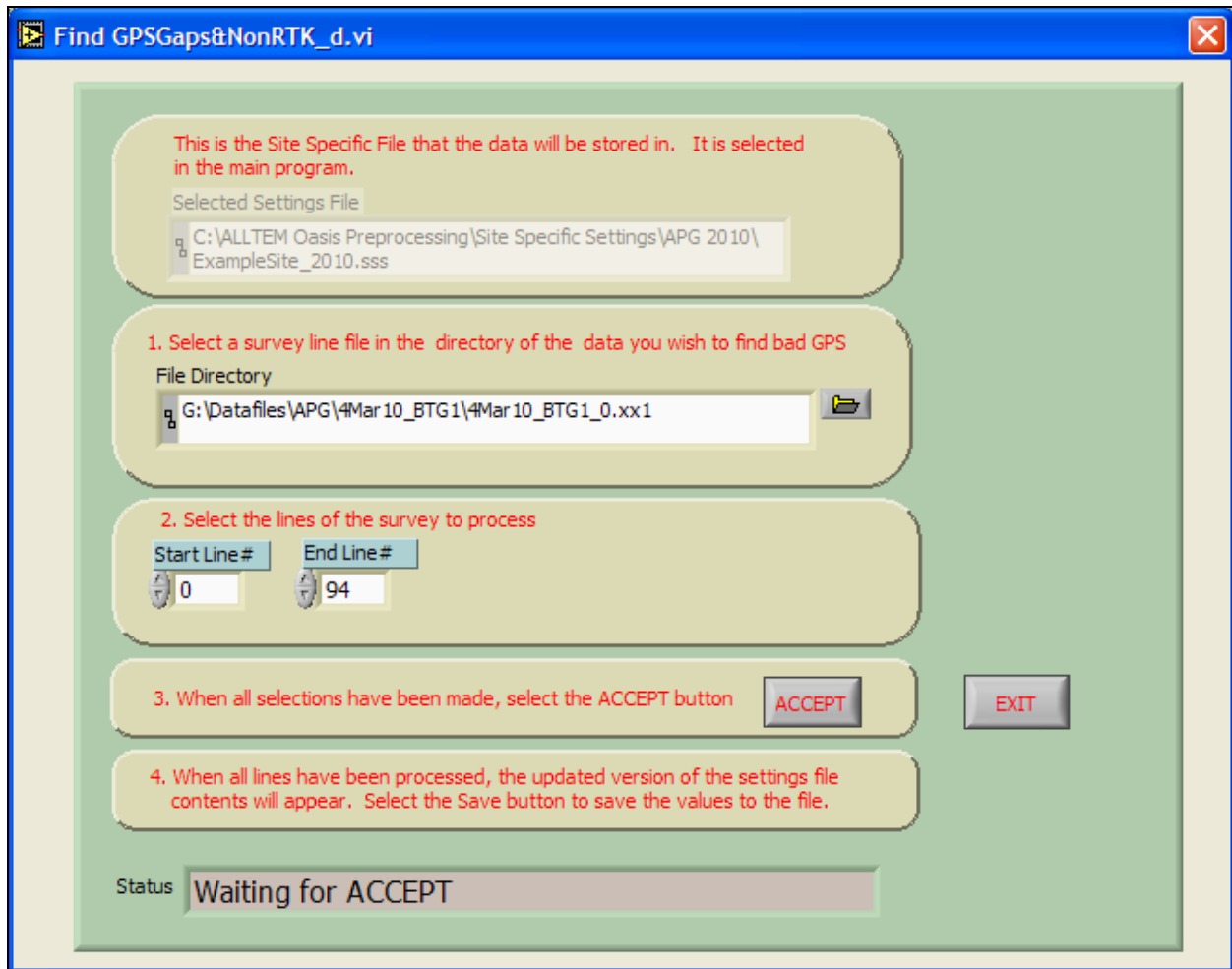
Figure 6.8. The **Find GPSGaps & NonRTK** window.

In the top field check to see that the Site Specific Settings file is the one that is intended. For the first time through a data set this may be the default file. If the ".sss" file is not the intended file, exit and repeat step 4 in the main program. If the ".sss" file is the intended one, do the indicated numbered steps in sequence. You may click on the browse icon to navigate to the desired data set and select any individual file, as before, to select the entire set of data. Choose the lines of the survey to process. If the ".sss" file chosen has flags to skip certain lines, they will be skipped in

this processing. Then click on **ACCEPT** to begin the scan to find missing or non-RTK_FX GPS data. When the scan has completed, a window will open that shows Site Specific Setting information including any missing or bad GPS data, as shown in Figure 6.9. This is the same as Figure 6.5 except that, in general, it may have different data.

Figure 6.9. The Site Specific Settings window.

The bad and missing GPS data locations are shown in the red fields "Do not edit items in RED boxes." on the right. The up/down buttons may be used to move through the locations where there are missing or bad GPS data. Use the up/down buttons in the leftmost column to look at the results, but **do not edit the numbers**. The first field under **MissingHeadGPS X** is the line number, "58". The second number designates the record number (data point) along line 58 where there was missing GPS data for the X polarity TX coil case. As mentioned above, missing GPS data are more serious than inaccurate (bad) GPS data. For the example data shown, line 79 had both bad and missing GPS. In the **BadGPS** fields for **X**, **Y**, and **Z**, the first number is the line number, and the second number is the Coordinated Universal Time (UTC). The UTC is used to associate corrected non-RTK_FX GPS data with the corresponding ALLTEM data record.

The red field at the lower left makes it possible to examine: the reconstructed GPS array (**Recon GPS Array**); the fill-in array (**Fill-In Array**); the UTC time; and the number (**UTC Breaks**),

locations (**Index**) and lengths (**Length**) of breaks in the UTC. Again, this information might be used to help reveal whether or not the reconstructions involved long gaps and it would be better to repeat the line/s, but the data in these arrays should not be edited. **If you decided to use these data, do not forget to click the "SAVE" or "SAVE AS" button.**

When the **"SAVE"** or **"SAVE AS"** has been clicked, a window will appear similar to that shown in Figure 6.10.
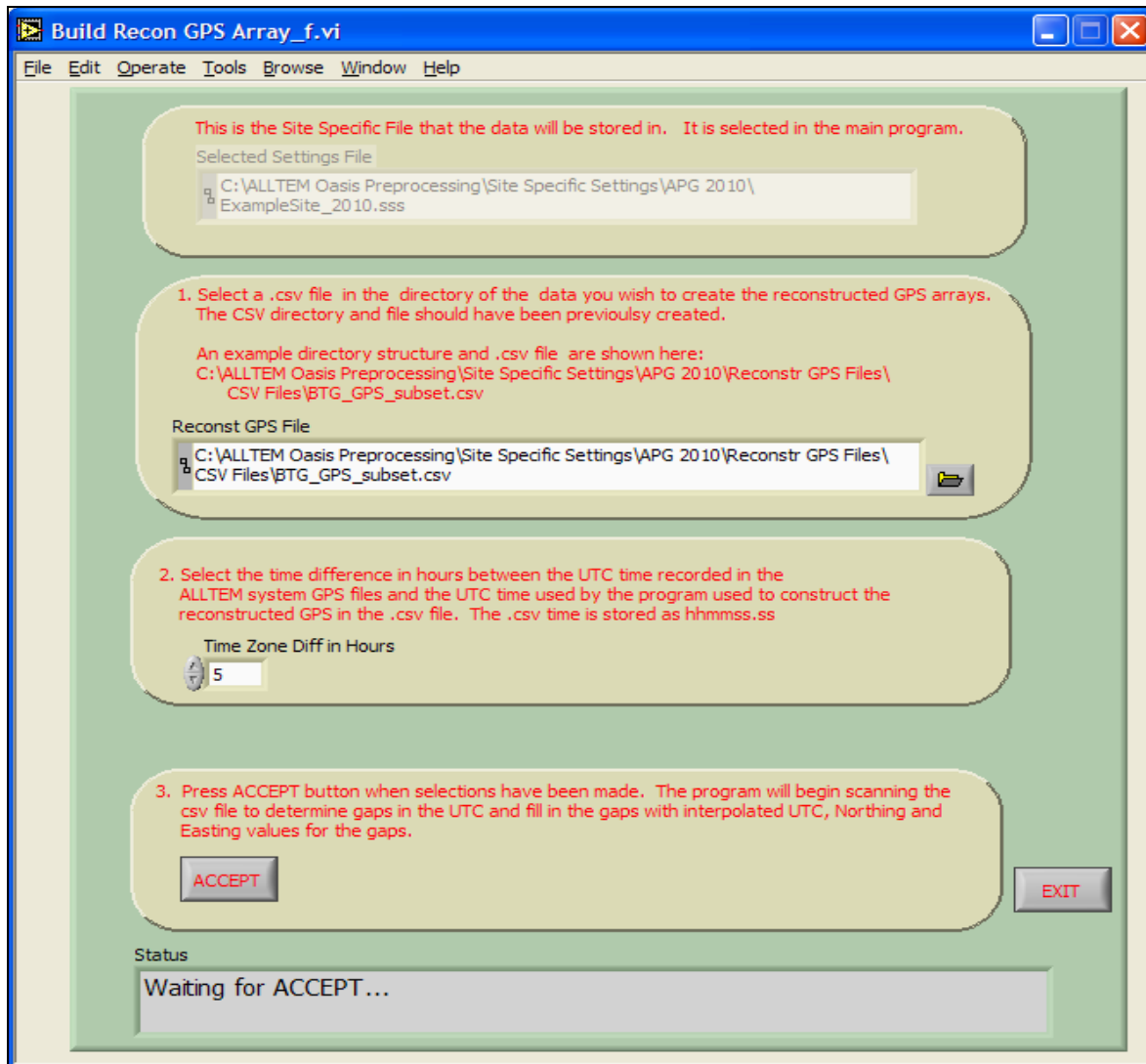
Figure 6.10. The **Build Recon GPS Array** window.

The top field of this window shows the Site Specific Settings file (".sss") where data will be stored. If this is not the correct file, it can be changed by clicking the **EXIT** button, stopping the program, starting it again and choosing the ".sss" file that is desired in accordance with step 4 above. In the field numbered "1" follow the directions. The ".csv" file that is referenced must have been previously created by a program other than this LabView program. If the name that appears in the field is not the one to be used, the browse icon allows for selecting the desired

".csv" file. When this is done, move to step 2 and enter the time zone offset from local time (at the location where the field data were acquired) and UTC. The time offset is available in many places on-line, for example, *http://hurricanes.noaa.gov/zulu-utc.html* [URL]. In our example data set the data were acquired at Aberdeen Proving Ground at a time of year when the local time was Eastern Standard Time (EST). The offset from EST to UTC is 5 hours. The reason for this step is that the program used to create the ".csv" file assumes UTC whereas in the ALLTEM data files local time is used. When the ".sss" file is verified and steps 1 and 2 are completed, click the **ACCEPT** button. When the position reconstruction processing is completed the site specific window (see Figure 6.9) will appear once again. If there is a previously saved ".sss" file with the same name you will be asked whether you want to overwrite that file, as shown in Figure 6.11. (The file being replaced in this example was named Test11-23A.sss) If you wish to overwrite, click on the **Replace** button. Otherwise, click on **Cancel**.

Figure 6.11. The Site Specific Settings file replacement window.

Step 8.   Accept settings

Click on the **Special Controls** tab (Figure 6.2) before selecting **ACCEPT SCREEN SETTINGS** to see whether the **Special Controls** tab has the correct settings. If not, correct the settings, click **ACCEPT SCREEN SETTINGS** and then click on the **Processing Screen** tab.

If you know that the **Special Controls** tab already has the desired settings there is no need to click on it. Just click on the **ACCEPT SCREEN SETTINGS** button at the lower right and immediately click on the **Processing Screen** tab.

6.3.2   Special Controls Tab

The **Special Controls** tab contains settings for the number of polarities to process, whether certain polarities are to be inverted or not, filter settings, an interpolation over an initial glitch, and an option for background subtraction mode. Most of these should not need to be altered, but options are made available. When selected, the tab looks like Figure 6.12.
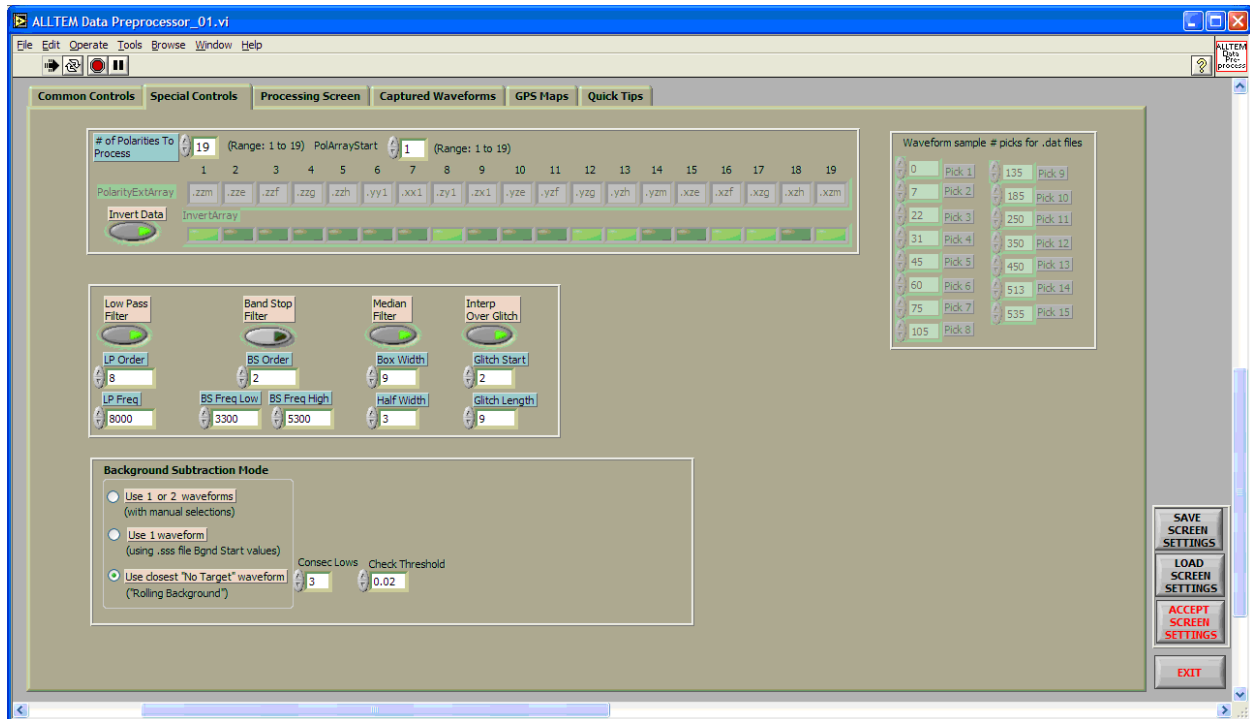
Figure 6.12. The Special Controls screen.

The first option, **# of Polarities to Process**, has an up/down selector button with a permitted range of 7 to 19. Normally all 19 polarities are processed, but as few as 7 may be processed. If fewer than 19 polarities are selected, the ones that are included are in the order shown. The first 7 polarities are regarded as essential to our inversion program. Including the others usually improves the inversion results. On the other hand, omitting polarities reduces the processing time. **It would be wise not to reduce the number of polarizations processed without testing the effects on inversion and classification,** perhaps on a subset of the data. Underneath the selector for the number of polarities to process is an **Invert Data** button and a row of illuminated indicators showing which polarities are inverted. This is for information and should not be changed. Certain polarities were inverted in order to make all of the single-polarity target responses positive. As a result, amplitude spatial plots of these channels all have the same, positive, polarity. Positive polarity is assumed by the inversion algorithm. Because some of the polarities are generated from the differences of outputs from coils measuring horizontal target response fields, these polarities inherently measure what amounts to a horizontal gradient and therefore will be positive or negative depending on whether the target is on one side or the other side of the center of the cube along the axis being measured. These horizontal-derivative polarities are not inverted. If the **Invert Data** button were turned off, the resulting preprocessed data would have the opposite polarity and this would not be compatible with the inversion algorithm, so we recommend leaving this button turned on, as shown.

To the right is a frame labeled **"Waveform sample # picks for .dat files."** This frame displays information only and cannot be edited. The number of samples and their locations have been chosen heuristically and work well for our inversion/classification processing algorithms and methods. Changes to these can only be done by going into the LabView program.

Under the polarities frame is a frame containing filter and glitch controls. The **Low Pass Filter**, **Band Stop Filter**, controls invoke LabView's zero-phase library filters. The values shown in this example have been chosen because they work best in most cases. Note that the **Band Stop Filter** is turned off by default because it causes an undesirable amount of distortion near the beginning and end of the resulting waveforms. We recommend using this filter only if the waveforms are contaminated by high levels of narrow-band noise, and the only way to suppress this noise is through a band-stop filter. If the band-stop filter must be used, experiment with the upper and lower frequencies and order of the filter to get the best compromise between noise rejection and waveform distortion. The **Median Filter** is a custom version of the standard LabVIEW median filter function. Instead of just choosing the middle value of the sorted array of length **Box Length**, the option is given to average a number of samples near the middle (**Half Width**) and return that value as the filtered result. Both the **Box Length** and **Half Width** should be chosen as odd numbers, and **Box Length** larger than **Half Width**. The last button in this frame, **Interp over Glitch,** is not a standard LabView function. It is there to circumvent a problem that arises when a background waveform is subtracted from a large-amplitude target waveform, resulting in a large positive-negative voltage transient (glitch) at the beginning of the waveform. The low-pass filter will smear the effects of this glitch into parts of the waveform used for the inversion/classification algorithm, producing anomalous results. The best solution is to remove the glitch by interpolating through it before the waveform is filtered. We therefore recommend that this button and the settings be kept as shown.

The frame at the bottom is **Background Subtraction Mode**. Early in ALLTEM development, we would record a few static waveforms at the beginning of each survey line before putting the system into motion. We would then use these averaged waveforms as the system- and ground-background response for the attendant line of recorded data. This approach is still available with the **Use Constant Waveform** option, selectable using the radio button. The more sophisticated rolling background method is preferred, especially for long survey lines. The TX and RX coils are rigidly mounted on the cube to avoid vibration-induced noise (microphonics), but thermally-induced changes in physical dimensions cannot be prevented. Changes in coil area or relative position cause changes in both TX field strength and RX received voltages. Such gradual changes are manifested in the data as drift. Another reason to use the rolling background method is that it can increase the response from small metallic targets . As the ALLTEM cube travels along the survey line, the distance between the cube and the ground beneath it will vary. The ALLTEM response is sensitive to this. As a result, if a single background waveform is used to correct the entire line, other "no target" areas along the line, where the cube to earth distance is different than where the background was taken, will show a small, square wave signal at the same 90 Hz drive frequency. The square wave can change polarities, depending on whether the cube is closer or further away from the ground. If the square wave is in the wrong direction at the time a small target is just coming under the cube, part of the amplitude from the target will be reduced by having to overcome the square wave. The rolling background method improves this by continually resetting the background waveform to the closest previous "no target" condition along the line. The values constraining the rolling background case under **Use closest "No Target" waveform** are: (1) the number of consecutive data points (**Consec Lows**) that have to be below (2) the selected threshold (**Check Threshold**). In the example shown here the choices are three consecutive waveforms that must be below the amplitude of 0.02 volt. The amplitude refers to the difference between waveform samples 31(near the beginning) and 513 (near the end). These specific values have generally produced good results, but they can be changed if

desired. If the density of targets is too high along any given line, no waveforms will meet the selection criteria, and thus no new backgrounds will be calculated. In this case the rolling background method may behave the same as subtracting a constant background, assuming no targets were present where the line started. This assumption is often not valid.

If the **Use Constant Waveform** case is chosen, the options (shown in Figure 6.13) change to **Start Wfrm #** and **# to Average**. In this example the value for **Start Wfrm #** is "0" and the value for **# to Average** is "3." Waveform number "0" assumes that the system was not over a target when the line was begun. It was our practice to record three or more waveforms at the beginning of each line while the system was stationary, and to average these waveforms for a background. If the average waveform seems to contain target responses, then it is necessary to examine the profiles (discussed below under the **Processing Screen** tab), visually select a place where it appears that there are no targets, come back to this screen to enter the appropriate location in the **Start Wfrm #** field, and then reprocess the line.
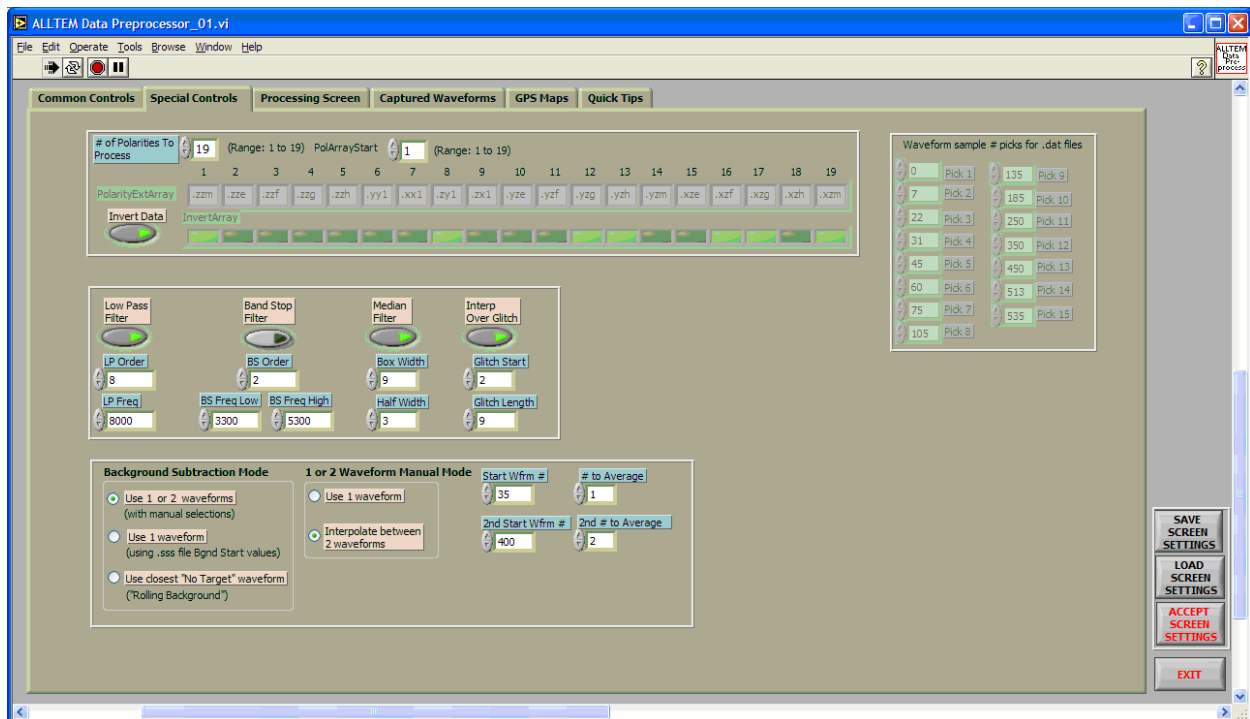
Figure 6.13. The **Special Controls** screen when the **Use constant waveform** option is selected.

6.3.3. Processing Screen

Clicking the ACCEPT SCREEN SETTINGS button from either the **Common Controls** tab or the **Special Controls** tab initiates data processing. The user can monitor the processing on the **Processing Screen** (the **Processing Screen** tab must first be manually selected by the user). A representative example of this screen is shown in Figure 6.14. There are two data displays and a number of options. The upper display is a profile plot of waveform amplitudes, for which the vertical axis is amplitude (volts), and the horizontal axis is record number along a particular line. The amplitude being displayed in this example is for the ZZM polarity. The amplitudes are the

differences between the measured waveform voltages (bottom display) at the locations of the yellow and red cursors. The horizontal axis on the bottom display is time in seconds. A yellow cursor in the top display is positioned at the record containing the waveform in the bottom display. Records may be selected by re-positioning the yellow cursor by dragging the small yellow slider on the X-axis to a different data record. When this is done the corresponding waveform will then appear in the bottom display. Data processing will proceed automatically through all the lines that were previously selected for processing, unless the option to freeze and
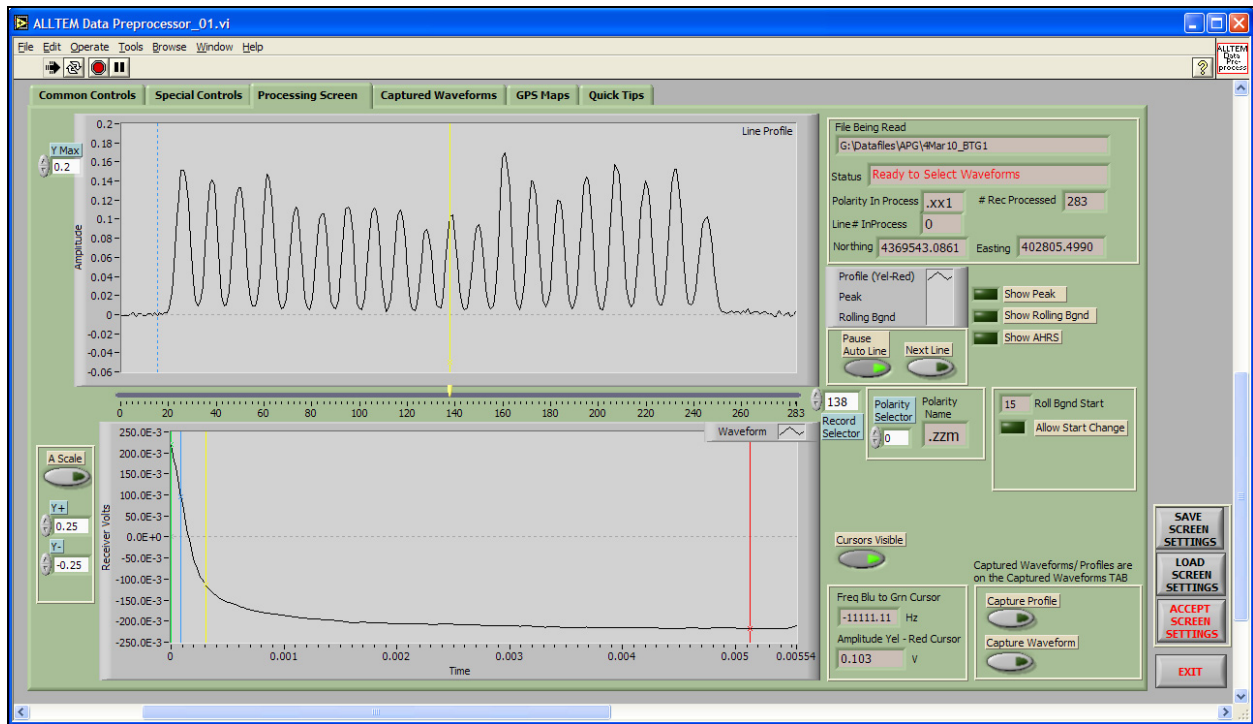
Figure 6.14. An example of the **Processing Screen**.

display each line has been selected. For this option click the **Pause Auto Line** button (shown illuminated in Figure 6.14). The operator may then single-step through the lines by repeatedly clicking the **Next Line** button, or may resume automatic operation by toggling the **Pause Auto Line** button off. If it is desired to save a set of profiles, the **Capture Profile** button can be clicked. This is best done while the **Pause Auto Line** button is selected. Viewing the saved profiles is discussed below. There is also a **Capture Waveform** button below that saves selected waveforms in the same way the **Capture Profile** button saves profiles.

The vertical scales on each data display may be adjusted so that all plotted values are on scale. On the **Line Profile** display, the bottom vertical scale value is adjusted by double-clicking on bottom vertical scale value and typing in a new value. Since most of the profile responses go only positive, the **Y Max** control is provided for easily controlling the upper vertical limit. It will override any value that has been manually typed in the upper vertical scale value. In the **Waveform** display the upper and lower limits may be adjusted by using the **Y+** or **Y-** controls or by clicking the automatic scale (**A Scale)** button, for a one-time auto scale. The **Y+** and **Y-** controls override any values that are manually typed in the vertical scale values. Note that the

plotted profile amplitude at the selected record number is less than the full waveform amplitude of the corresponding waveform below because the profile amplitudes are the differences between the voltages at the locations of the yellow and red cursors in the **Waveform** display. The locations of the yellow and red cursors correspond to the beginning and ending sample times that are used in the inversion/classification processing. Earlier and later times are avoided because the waveform may have been distorted by waveform filtering (discussed above).

The particular profile shown in Figure 6.14 is a case where the system gathered data along, but not centered on, a line marked by similar steel balls. The amplitudes are all relatively low and evenly spaced.

To the right of the **Line Profile** display is a frame with several fields. The top field, entitled **File Being Read,** displays the name of the file, including path, that is being processed. If this is not the intended data file, stop the program (click on the red stop-sign icon in the menu bar), restart it (click on the run-arrow icon in the menu bar) and proceed to select the correct data file (step 2 in the **Common Controls** tab). The next field down is the **Status** display that indicates what the program is doing. Under the status field are five more fields: (1) **Polarity in Process** will increment through all polarities that have been chosen for processing under the **Special Controls** tab; (2) The **# Rec Processed** field will show the number of records processed and at the completion of processing of each line will contain the number of records in that line. This number should agree with the right end of the scale under the top display; The (4) Northing and (5) Easting fields show the coordinates that correspond to the yellow cursor on the **Line Profile** display. The Northing and Easting, the record selector field value and the waveform on the bottom display will change as the yellow slider that controls the position of the yellow cursor is moved along the profile.

Under the **File Being Read** frame is a display that says **Profile (Yel-Red)** and under that **Peak**, and **Rolling Bgnd**. The **Peak** and **Rolling Bgnd** have control buttons next to them (**Show Peak** (red line) and **Show Rolling Bgnd** (green line)**)** for controlling whether that information shows up on the **Line Profile** display. Both buttons are enabled in Figure 6.15.

The green line (rolling background) is binary, that is, low or high. When the green line is high new background values are being calculated and used, because the rolling background algorithm has determined that the signal is below the selected threshold voltage (see the discussion under the **Special Controls** tab above) and there have been the selected number of consecutive values under this threshold. In the example given above, these values were set at 3 consecutive lows and the voltage threshold was set to 0.02 V. When the line is low, no new background is calculated, and the last previously calculated value is being used. This is the case when a target signal or noise pushes the voltage above the selected signal voltage threshold. Note that the rolling background algorithm operates on each polarity independently, as may be observed by using the **Polarity Selector** button, below, to move through the various polarities.
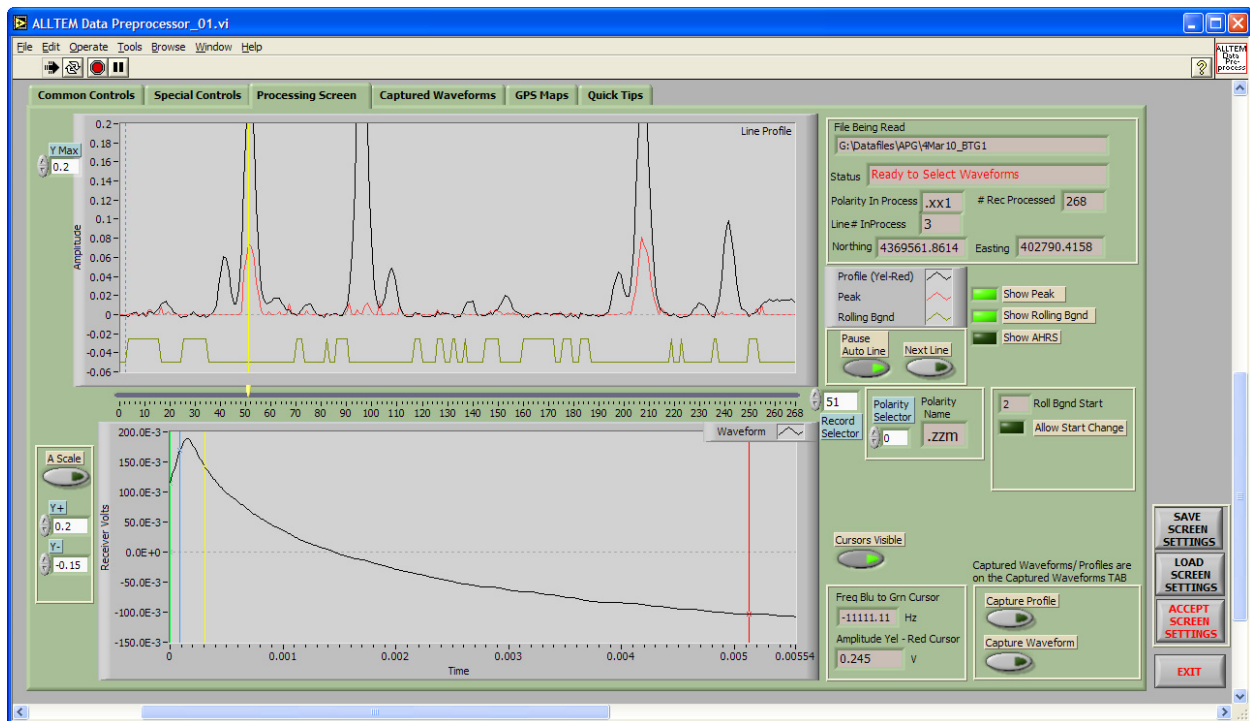
Figure 6.15. The **Processing Screen** display when the **Show Rolling Bgnd** and **Show Peak** buttons are clicked.

The red line (peak value) is calculated for each waveform by measuring the amount the waveform initially peaks after sample 0, before it later begins to decline. Record #51 is selected in the **Line Profile** and **Waveform** displays to show a waveform that has a non-zero peak value. This peak amount is then normalized by dividing it by the waveform amplitude between samples 31 and 513. This ratio is useful for detecting non-ferrous content in the metallic object being measured. When the object is completely non-ferrous, the peak value will be almost as large as the sample 31 to 513 amplitude. Mixed ferrous-non-ferrous objects will have a smaller peak value. There may sometimes be apparent non-zero peak values around the beginning and end of large targets on the line profile (for instance around records # 90 and # 105). These may not actually indicate non-ferrous content but are artifacts of the transition the waveform goes through when having to overcome the state of the ground induced, small square wave, which is always present as the cart height above the ground varies along the line.

The frame to the left of the **Show AHRS** button has two buttons that have been previously mentioned: **Pause Auto Line** and **Next Line**. To reiterate, the **Pause Auto Line** button, when illuminated, will stop the processing when the processing has completed for the current line. This is useful when it is desired to examine profiles and waveforms for the current line for the various polarities before allowing the processing to continue. The operator can then single-step the processing through the lines by repeated use of the **Next Line** button, or can resume fully automatic processing by toggling the **Pause Auto Line** button off.

When the **Pause Auto Line** button is active, a given record in the current line may be selected for examination in one of three ways: 1) the yellow slider on the record number scale under the **Line Profile** display can be dragged with the mouse, 2) the up/down **Record Selector** button may be clicked, and 3) the desired record number may be typed into the adjacent field.

The dashed blue line in the **Line Profile** display indicates the waveform record number that was used for the Rolling Background Start (**Roll Bgnd Start** field in mid-right of the screen). For a given line, the start value will reflect the value used for the particular polarity being displayed. A description of how to manually change the value is described below, in the discussion for Figure 6.18.

To the right is a **Polarity Selector** up/down button with a numerical field and, to the right, a **Polarity Name** indicator. The polarity number may take values from 0 through 18 if all 19 polarities are being processed, or a lower maximum number if fewer polarities are being processed (see the **# of Polarities to Process** discussion in section 6.3.2, **Special Controls** tab). To see what the profiles and waveforms look like for the various polarities, use the **Pause Auto Line** button, then click the up/down **Polarity Selector** button and observe the changes in the profiles and respective waveforms for some target of interest. The **Polarity Name** field will show what polarity is being displayed. To the right are three indicators that show the start points for the rolling background. Notice that these are, in general, different for the Z, Y, and X polarities.

For certain polarizations, target responses may have both positive and negative amplitudes, analogous to ferrous target responses for magnetometers. In figures 6.16 and 6.17 we show an example for the YY1 polarity (the polarity naming convention is discussed in the ALLTEM system hardware manual). In Figure 6.16 we see that target responses in the **Line Profile** display go both positive and negative and target locations are approximately under the center (zero crossings) of the responses. The waveform is initially positive for record number 114. Note that in Figure 6.17, where the slider has been moved to record number 117, the initial waveform response is negative.
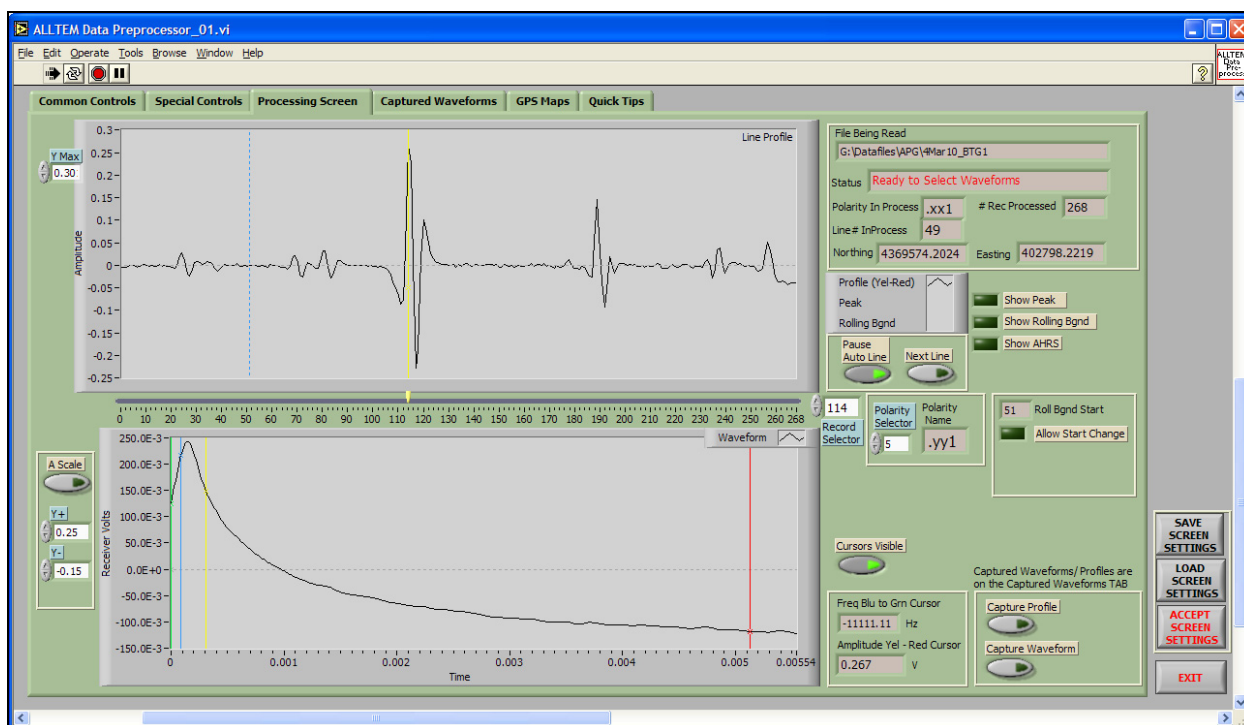
Figure 6.16. Target responses on line 49 for polarity YY1 and record number 114.

Figure 6.17. Negative polarity waveform response for record number 117.

In the lower left of the screen is a notation, "Captured Waveforms/Profiles are on the Captured Waveforms TAB." This will be discussed below.

Under this notation is a frame with the **Cursors Visible** button and the **Capture Waveform** button. The **Cursors Visible** button is normally illuminated. It can be clicked off to remove the yellow, red, blue and green cursors on the lower display. Note that this button does not affect the yellow cursor on the upper display which is always visible. The **Capture Waveform** button, when clicked, saves the waveform currently shown on the lower display and may be used repeatedly for various polarizations at one record number, or for various record numbers.

If, during processing, it is observed that noise at a given frequency seems to be present on a waveform, the blue and green cursors can be set at the beginning and end of one cycle of the noise. If this is done, the frequency of the noise between the cursors will be calculated. Experience with the ALLTEM waveforms has shown that there is sometimes a noise frequency on the waveforms in the region between 3 and 5 Khz. This frequency range is normally the one that is selected if the **Band Stop Filter** is used when processing the data**.** The yellow and red cursors have been discussed already and are set to positions far enough from the beginning and end of the waveform that the effects of the filters on the waveform should not be significant.

At the lower left corner of the upper display is the **Show AHRS** button that enables display of the attitude heading reference system data as illustrated in Figure 6.18.

Figure 6.18. **Processing Screen** with the AHRS data shown below the profile data, and **Allow Start Change** enabled.

The AHRS data are displayed at the bottom of the upper display. For this particular line the scale in degrees is +5.0 degrees to -10.0 degrees. Note that the roll (side to side) motion of the cart (black trace) is more rapid and of greater amplitude than the pitch (fore and aft) motion (red). This is natural because the fore and aft wheelbase of the cart exceeds the side-to-side spacing of the rear wheels. The AHRS data are recorded as part of the data, but as of this writing have not been folded into the data processing. If the AHRS data were folded into the processing it is possible that some improvement might be observed in target inversion/classification performance on sites that have a rough surface and the roughness scale is close to the size of the cart.

To the right of the **Polarity Name** indicator is a frame with two control buttons and an indicator. The **Roll Bgnd Start** (Rolling Background Start) indicator shows the waveform record # that is being used as a "quiet" area for the first pass of the rolling background subtraction function. On a given line, it will change to the polarity appropriate value contained in the Rolling Background Start Array entry in the .sss file. If no background subtraction is being performed, or if "use 1 or 2 waveforms (with manual selections)" is being used, the frame will be empty. If the particular start value produces a profile that has a significant non-zero value where it is thought that no metallic items are present ("quiet area"), then it may be necessary to adjust the start value. This is done by moving the yellow cursor to a record # that is thought to be "quiet" (record # 130 in Figure 6.18). Then click the **Allow Start Change** control. This will cause the **Accept New Start** button to become visible. Click this button to change the start value. When this is done a message will appear in a pop-up dialog box that will ask to confirm changing the particular .sss file that is being used (not shown). Click **Replace** to overwrite the file or **Cancel** to reject. If **Cancel** is chosen, a prompt to **Continue** or **Stop** will appear. Clicking **Continue** will continue the program operation, clicking **Stop** will stop the program. If **Replace** or **Continue** is chosen, an additional field will appear under the **Accept New Start** field named **Roll Bgnd Start Old** (not shown). This will contain the start value before the change was made. This is provided as history, if you want to go back to the original value. Also, if **Replace** is chosen, the blue dashed vertical line will move to the location of the yellow cursor, indicating the new start value. If you anticipate a lot of changes, it is advised that a backup copy of the current .sss file be made, in case you want to revert to the original values. It should be noted that the changes to the start value will not immediately change the offset on the profile. The program must be stopped and restarted to see the effects of the change.

6.3.4. Captured Waveforms Screen

Waveforms that are captured using the **Capture Profile** and **Capture Waveforms** buttons while the data are being processed and displayed under the **Processing Screen** tab may be displayed under this tab. One example is shown in Figure 6.19.
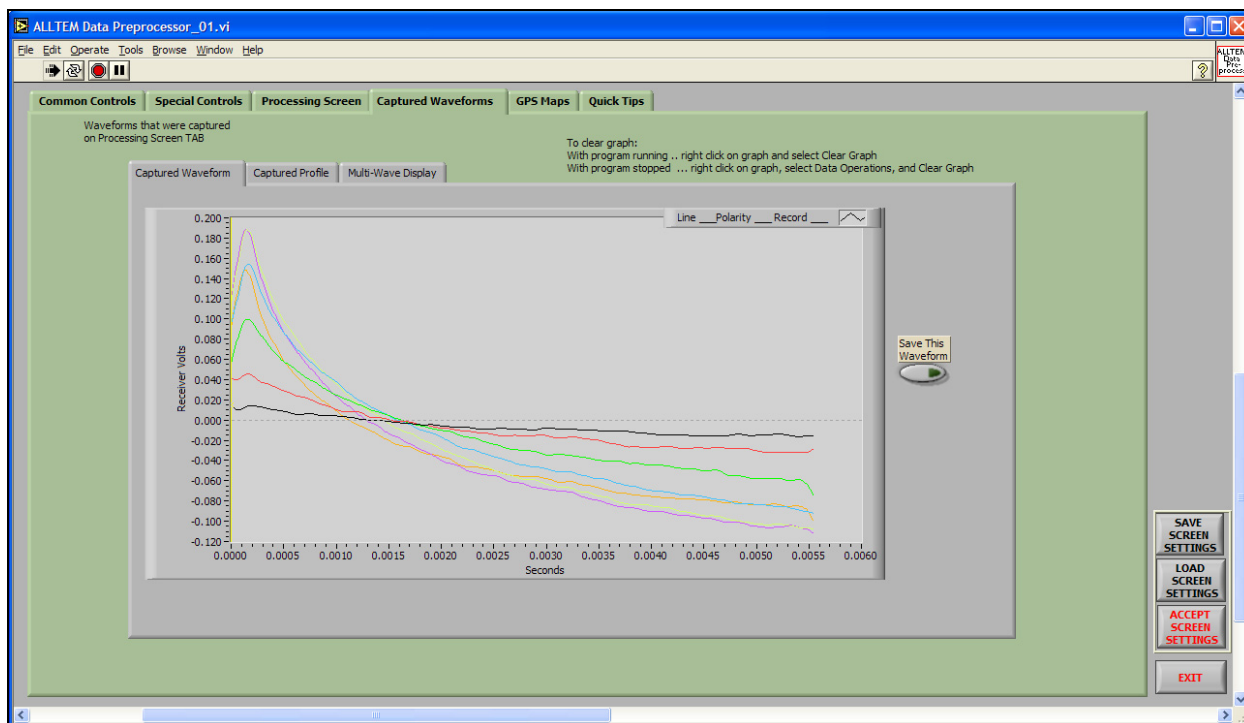
Figure 6.19. An example of the **Captured Waveforms** screen.

Under the **Captured Waveforms** tab the display is controlled by three tabs. The first has the same name as the parent tab. Figure 6.19 shows an example of a number of different polarity waveforms from one record over a single target. Another use of this display might be to show waveforms from one polarity over several targets or from different records over one target. The second tab is named **Captured Profile** and an example is shown in Figure 6.20. The final tab, **Multi-Wave Display** shows a range of waveforms around the currently selected waveform shown on the bottom display of the **Processing Screen** tab as in Figure 6.21.
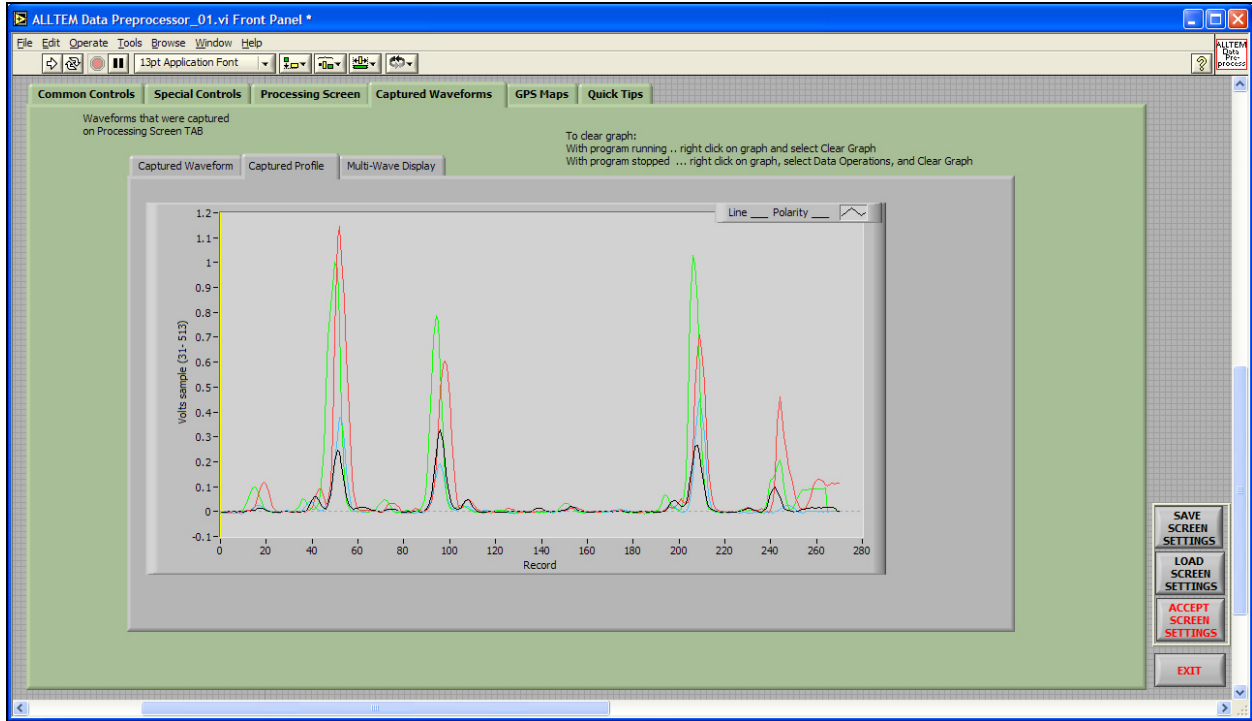
Figure 6.20. Overlaid profiles for several TX-RX polarizations.
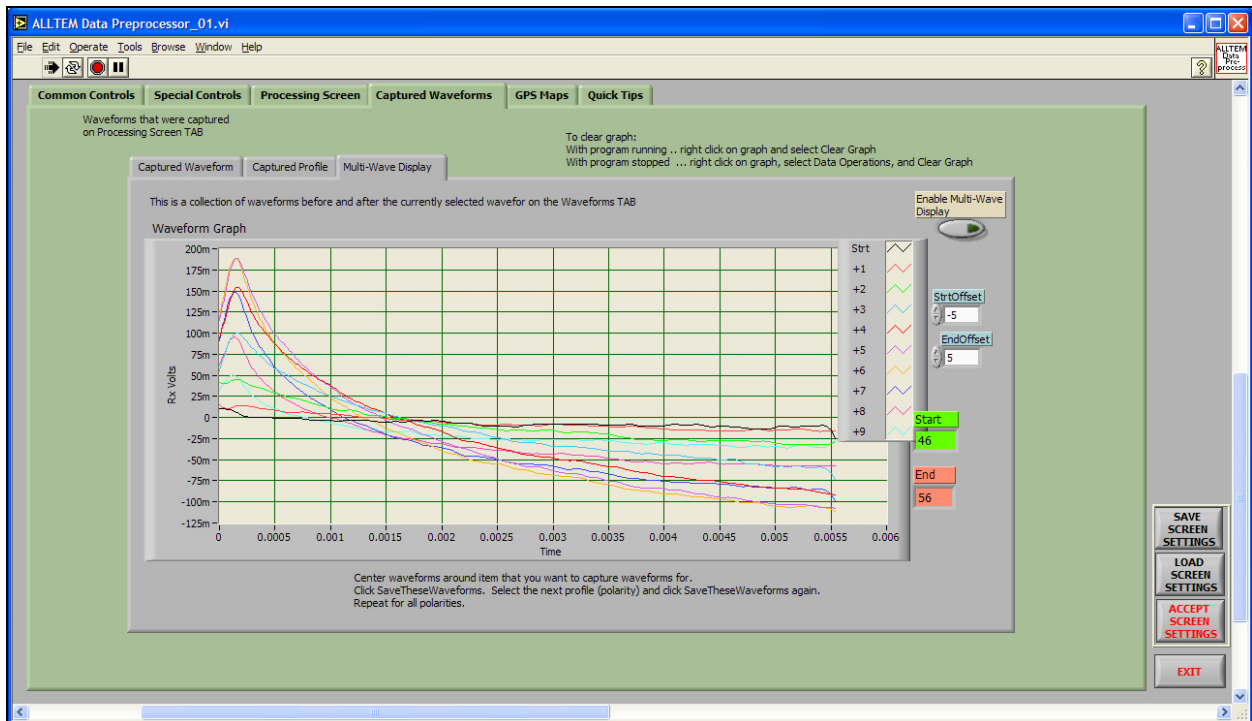
Figure 6.21. Four waveforms before and four after record number 51.

The number of waveforms displayed by the **Multi-Wave Display** can be changed using the **StrtOffset** and **EndOffset** up/down buttons, or with values typed in the corresponding fields. Any number may be entered, but normally a maximum of +/- 5 offsets from the selected waveform is sufficient. If a larger number is selected the display colors will repeat. To take a sequential look at waveforms for different polarizations, choose the desired polarization in the **Processing Screen** tab, move the slider to position the yellow cursor on the desired record number where a target of interest is located, then move to **Captured Waveforms** with the **Multi-Wave Display** tab selected. Then click the **Enable Multi-Wave Display** button. One can move back and forth between the **Processing Screen** tab and the **Multi-Wave Display.** For each new polarization or location click the **Enable Multi-Wave Display** button.

In Figure 6.19 a **Save This Waveform** button is shown. If this button is clicked a **Choose File to Write** screen will come up. The operator can change the directory and choose the name of the file to be saved. The file will contain an array of 555 rows and as many columns as the number of waveforms that are displayed. The ASCII array elements are the voltage values at each of the 555 time-samples of each waveform. The array file can be read into Excel (Microsoft), Oasis montaj (Geosoft) or another program for display.

6.3.5 Quick Tips

Click on the Quick Tips tab for tips about the use of this preprocessing program and descriptions of what the program is doing. Fuller descriptions of the LabView code are given Appendix 1.

6.3.6 Common Controls – Calibration Balls Case

Many of the steps for processing data collected with the calibration balls are carried out in the same way as for survey line data, but with some differences. We will highlight the differences here and refer the operator to sections beginning at 6.3.1 for those steps that are carried out in the same way.

When the **Calibration Ball** radio button is clicked on the **Common Controls** tab screen the screen will change, as shown below in Figure 6.22. Note that there are new options. The first is **Calibration Ball Location** and the second is **Ball Material**, which is either stainless steel or brass. Each calibration ball is placed in three different fixed locations because multiple locations are needed to provide good responses for all of the 19 polarization combinations. Note that in Figure 6.22 the file shown under **File Selector** is one of the survey line data files. This file does not have calibration data in it. Use the browse icon just to the right of the **File Selector** field to bring up the directory that has the calibration files in it. In this example, the calibration files were placed in the same directory as the survey line files. However, they can be placed anywhere and will need to be found and selected. In the example in Figure 6.23 the selected file name contains "SSX", which denotes the stainless steel calibration ball in the X position. The destination folder for the processed data can be changed at the top using the Windows folder select icon. Figure 6.24 shows the **Common Controls** tab after the calibration file has been selected and the **Extra Identifier** field has been cleared.
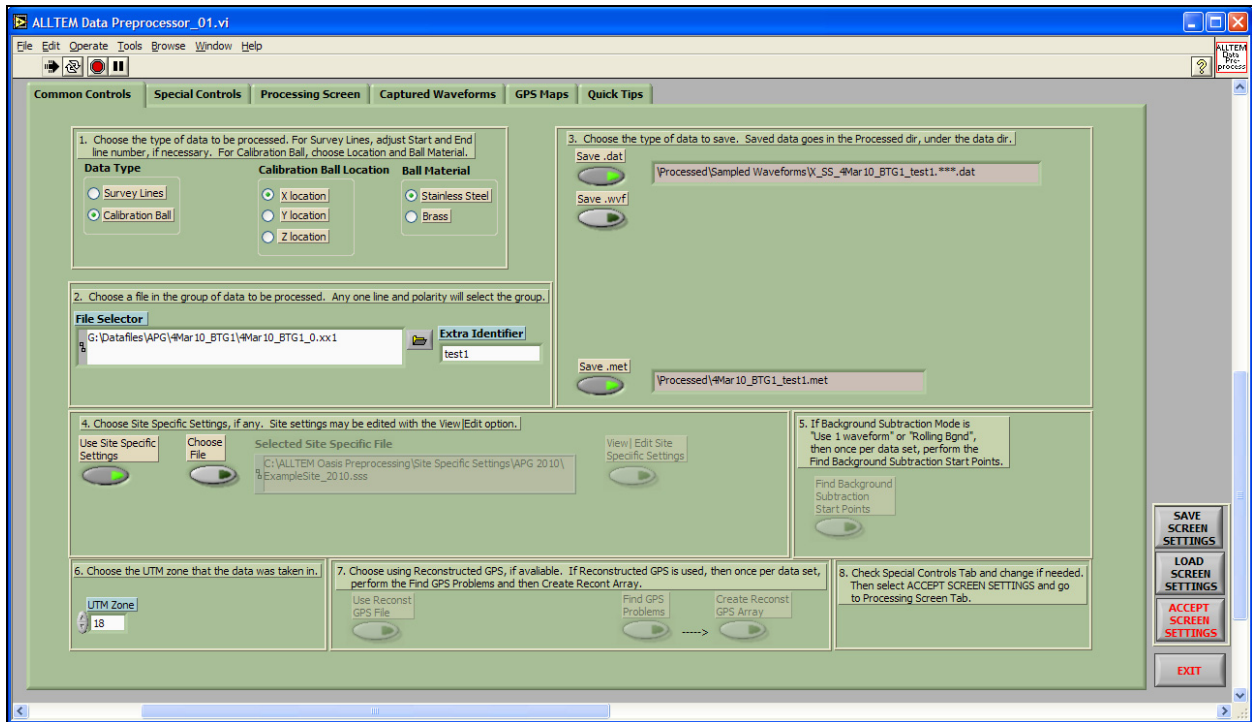
Figure 6.22. The **Common Controls** tab when the data type is **Calibration Ball**.
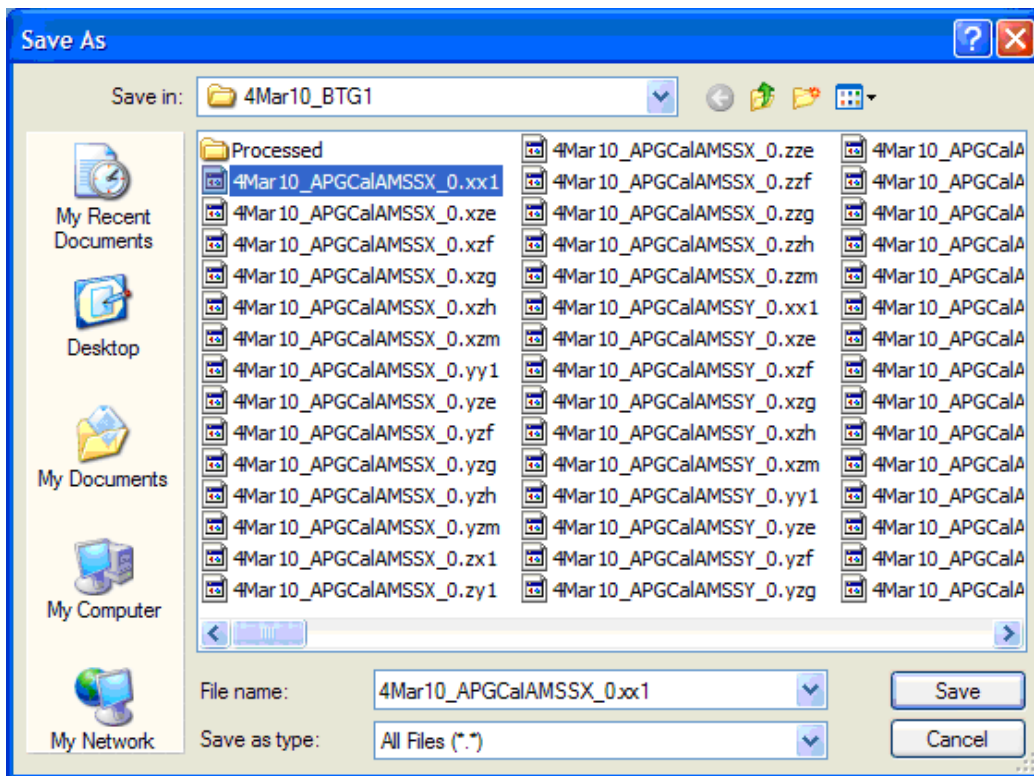
Figure 6.23. This shows a selected calibration file "4Mar10_APGCalAMSSX_0.xx1" taken on the morning of March 4, 2010.
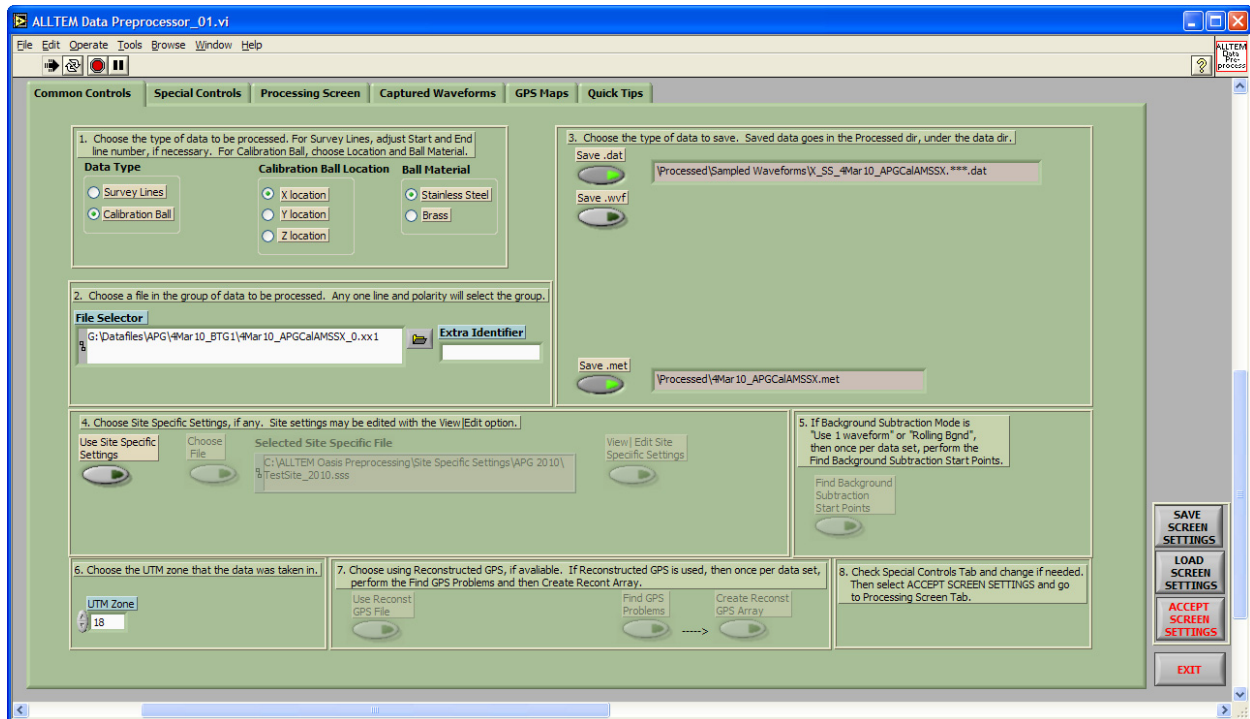
Figure 6.24. In this **Common Controls** tab screen the calibration file has been selected.

When the file selected under step 2 agrees with the location and material type in step 1, choose the type of data to be saved in step 3. **Important note**: In step 4, the **Use Site Specific Settings** button has been deselected because **Site Specific Settings** relate to survey line data, **not** to calibration data. When these steps have been carried out click on **Accept Screen Settings** and then go to the **Processing Screen** tab. The settings in the **Special Controls** tab may need to be changed for the **Background Subtraction Mode**. For calibration data, the mode should be set to those as shown in Figure 6.12, with the exception that the "use 1 waveform" button should be selected, rather than "Interpolate between 2 waveforms" shown in the figure. The "Start Waveform # of should be selected to be taken at a time well before the calibration ball was placed on the calibration fixture. The value of "35" in Figure 6.12 is usually a good initial choice. An example **Processing Screen** is shown in figures 6.25 and 6.26. In Figure 6.25 the yellow cursor in the top display is at record number 54, before the ball was put in place. In the lower display it is seen that the waveform – which is the sum of any system noise and external noise – has an amplitude of about +/- 2 mV, except near the beginning and near the end of the waveform where the low-pass filter introduced edge-effects. This level of noise is typical unless there are strong noise sources at the site. Also note that the blue and green cursors in the lower display have been approximately placed around one cycle of the noise and that the frequency shown in the adjacent field is 4 kHz. The cursors can be moved to span various cyclical variations in the waveform. When this is done the calculated frequencies are mostly in the 1 kHz to 4 kHz range, well within the band of the low-pass filter that has a corner frequency of 8 kHz (see Figure 6.13). Note that the noise might be further reduced by adjusting and turning on the band-stop filter (discussed above), but doing so distorts the waveforms and should not be done unless the noise is much greater than the +/- 2 mV observed here.
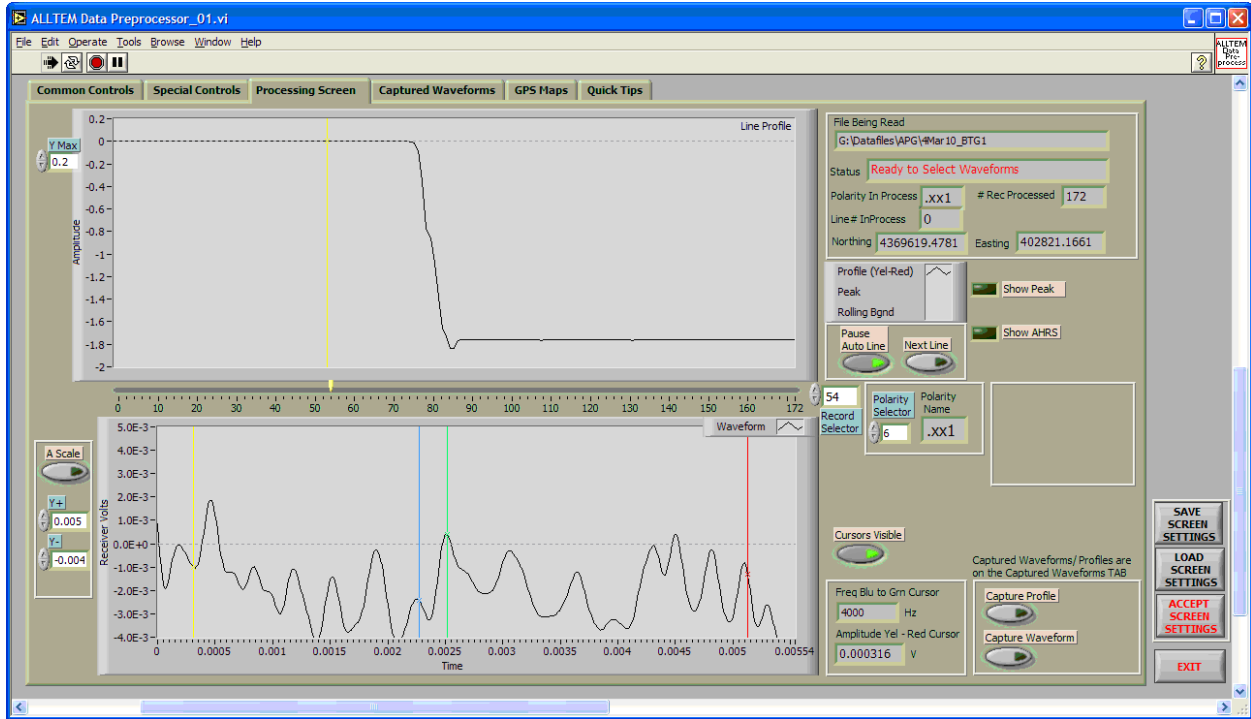
Figure 6.25. In this example the yellow cursor in the top display is set at record number 54, before the calibration ball has been put in place. The lower display shows only noise.
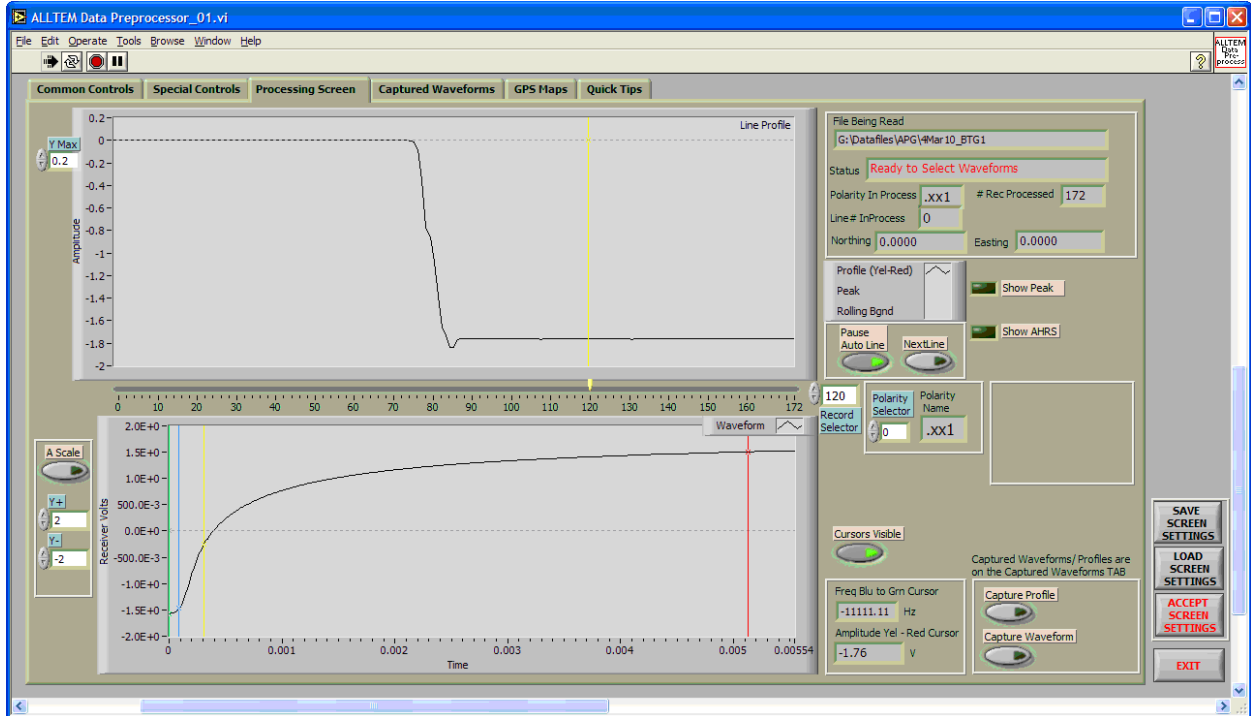
Figure 6.26. This figure is the same as Figure 6.25 except that the yellow cursor has been moved to record number 120, after the stainless steel calibration ball has been put in place.

In Figure 6.26 we see that the waveform has an amplitude of about 3 volts from minimum to maximum and thus is about 1,000 times (60 dB) greater than the noise. This is large enough to provide good calibration factors. The polarization being observed here is XX1 which should be strongly excited for a calibration ball in the X-position.

Process each location, X, Y, and Z for each material type. The **Captured Waveforms** controls work just as they do for the survey line data.

7.0   GEOSOFT OASIS MONTAJ ALLTEM DATA PROCESSING

A series of tools have been developed to assist in processing and interpreting ALLTEM data. These tools have been developed for users of the Microsoft Windows operating system only; as such all discussion in this document assumes this environment.

The processing of ALLTEM data follows the following flow. Raw data is passed through a preprocessing program written in LabView. The output of the LabView program is 23 tab delimited ASCII files.

These preprocessed data files may then be directly imported into Oasis Montaj for analysis and further processing. This document currently discusses only the Oasis Montaj processing portion of the data flow.

7.1   Setup and Installation

To begin several programs need to be installed to use the tools developed for ALLTEM data analysis.

7.1.1   Installing ALLTEM Components in Oasis montaj

Geosoft's Oasis montaj environment forms the backbone of ALLTEM data analysis. Interactive data manipulation as well as gridding and visualization tools are used extensively from Oasis montaj. These tools were developed using Oasis Montaj Version 7.2. Compatibility with other versions is not guaranteed. Please refer to the installation instructions from your copy of Oasis montaj.

Several GXs have been exclusively developed and must be included in your working copy of Oasis montaj. These GX's may be found in the folder labeled GX within the distribution folder. To make these available to Oasis simply move or copy these GXs into the *gx* directory located within your installation. Make sure to copy the contents of the folder, and not the folder itself or Oasis will not find these GXs. Typically this path is:

 C:\Program Files\Geosoft\Oasis montaj\gx

The GX's that must be placed there are:

usgs_alltem_analytic
usgs_alltem_apars
usgs_alltem_butterworth
usgs_alltem_classify
usgs_alltem_dccor
usgs_alltem_directgrid
usgs_alltem_drift
usgs_alltem_flip
usgs_alltem_gridfilter

usgs_alltem_import
usgs_alltem_int
usgs_alltem_invres
usgs_alltem_invrun
usgs_alltem_invset
usgs_alltem_loadstats
usgs_alltem_maskdata
usgs_alltem_masklines
usgs_alltem_neural
usgs_alltem_patchanalysis
usgs_alltem_patchanalysiscallr
usgs_alltem_patches
usgs_alltem_polydef
usgs_alltem_rangrid
usgs_alltem_redrawpatch
usgs_alltem_setclassify
usgs_alltem_smoothdata
usgs_alltem_targetfree
usgs_alltem_targetpick
usgs_alltem_uxlag2
usgs_alltem_wingrid
chsubsetoverwrite
mergelines

These gx's are outlined in the appendices of this report.

Also the menu files *alltem.omn*, and *alltem.smn* located in the *omn* directory of the release must be placed in the *omn* directory of your Oasis Montaj installation. Typically the path for this folder will be:

C:\Program Files\Geosoft\Oasis montaj\omn

7.1.1.1 ALLTEMDIR Directory

The folder *ALLTEMDIR* within this release must be placed in the Oasis Montaj\user folder. Typically this will be at the path

C:\Program Files\Geosoft\Oasis montaj\user

This folder contains scripts and control files which are used by the target picking program as well as a binary executable APARS_VX.exe program.

Within *ALLTEMDIR* there are several files and directories that must be treated with care. The directory *ALLTEMDIR\APARS_BIN* must contain a singe executable file which performs position based refinements to positions via AHARS sensor data. The directory *ALLTEMDIR\Cube_Def* should contain a single *.def* file that is used by the Apars executable.

This file is self-documented with any lines starting with '//' being a comment. Similarly the directory *ALLTEMDIR\Wagon_Def* should contain a standard *.def* file outlining the wagon geometry. Do not add more than one file to any of these folders. The rest of the files are scripts whose names or locations should not be changed.

7.1.2   Installing Python

Several scripts and tools have been developed using the Python language. As of version 7.0 Oasis Montaj ships and requires Python and as such it should already be installed on your machine.   If for some reason you do not have Python installed, it is freely available at www.python.org or in the bin folder of this distribution.   To install, simply double click on the *msi* installer.

If you are going to use Python 2.4 as shipped from Oasis open the Python installation directory, generally *C:\Python24* and right click on the *python2.exe* executable and select make shortcut. Rename this shortcut simply *python.exe*.

If you install Python 2.5-2.7 you will not need to make the above shortcut. There is no harm in having two copies installed on your machine. Do not remove Python24 after installing Python25 however, as this may harm your local copy of Oasis. Note that these scripts are not compatible with Python 3000.

Then you will need to add the interpreter to your path. This can be done by:

1) Right click on **My Computer**. Click on **Properties**.
2) Click on the **Advanced** Tab
3) Click on the **Environmental Variables** button
4) In the **System Variables** dropdown list, select **Path** (or **PATH**). Push **Edit**.
5) A popup named **Edit System Variable** will appear with the variable name set to **Path**.
6) The variable value textbox contains a semicolon separated list.
7) Append this list with the location of your Python installation. Typically this will be *C:\Python24* or *C:\Python25*.
8) Check that the above worked, click on **Start → Run** on your windows screen. Enter python as in
9) Figure (a). A python window should be launched
10) Figure (b). Alternatively you may enter python in a command prompt terminal as well.

<div align="center">

(a) **(b)**

</div>
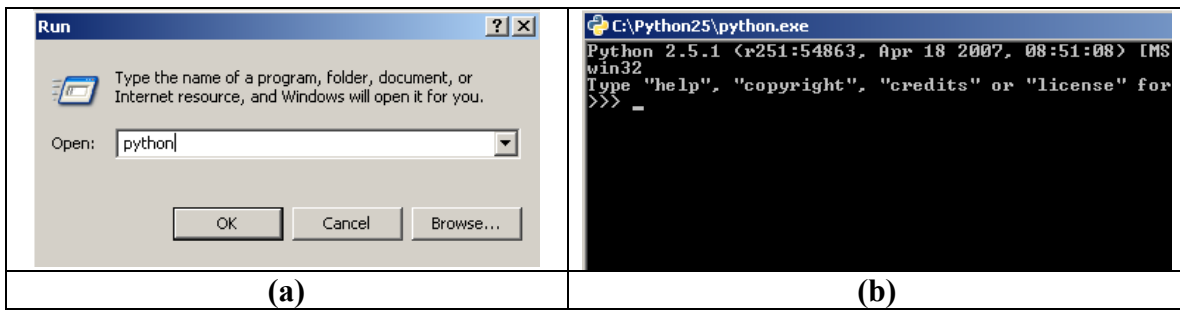
Figure 7.1. Simply calling "python" from Run or a Command line should launch a Python interpreter (b).

Additionally two modules need to be installed; these are called **matplotlib** and **numpy**. Binary releases are located in the bin directory of this release and are called *numpy-1.1.0-win32-superpack-python2.5.exe* and *matplotlib-0.98.1.win32-py2.5.exe*. Both 2.5 and 2.4 versions are included in the bin folder. Choose the ones that match your installation version of python. Install numpy before matplotlib. You can check that these modules have been installed by running python, **Start → Run → Python**. In the launched window, type:

```
Import numpy, pylab
```

Press enter. There should be no warning or errors shown, as displayed in Figure .
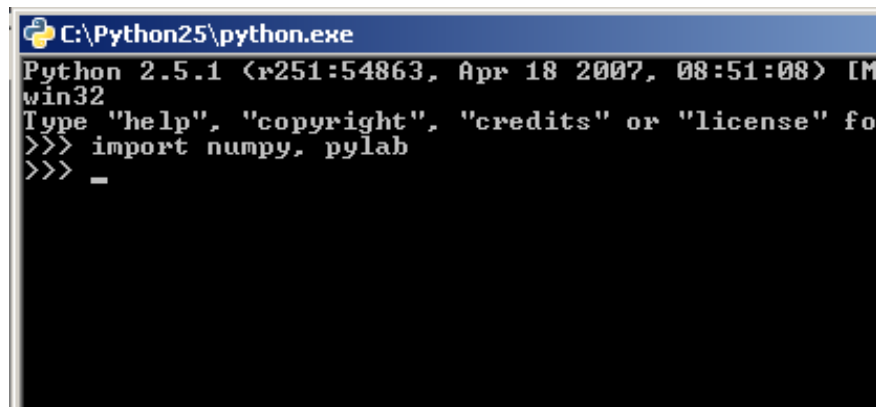
Figure 7.2. If the modules were properly installed, you will be able to import these modules as shown.

As of Oasis montaj 7.0.1 the programs contained in the path variable are not always found properly. The bug has been identified by Geosoft, and will hopefully be rectified in future releases. In order to call Python, copy the python executable file *python.exe*, from the install directory into *Geosoft\Oasis montaj\bin*. Do not create a shortcut (this doesn't work) and do not simply move the *python.exe* file into the Oasis Directory.

7.1.3   Installing the R Statistics Package

The statistical package **R** is also required to be installed. It is freely available for download at www.r-project.org and is also included in the '*bin*' folder of this release. Installation amounts to double clicking on the *R-2.7.0-win.exe* binary. Newer releases than this should work as well. The R interpreter must also be located in your system's path. This may be accomplished in roughly the same manner as for Python above:

1) Right click on **My Computer**. Click on **Properties**.
2) Click on the **Advanced** Tab
3) Click on the **Environmental Variables** button
4) In the **System Variables** dropdown list, select **Path** (or **PATH**), select **Edit**.
5) A popup named **Edit System Variable** will appear with the variable name set to **Path**.
6) The variable value textbox contains a semicolon separated list.
7) Append this list with the location of your Python installation. Typically this will be *C:\Program Files\R\R-2.7.0\bin*. Note that the path must point to the bin directory within R!
8) Check that the installation worked. Select **Start → Run** and enter "R". The output should be similar to
9) Figure . Once R has started you may exit by typing the command q()**.**

(a)	(b)
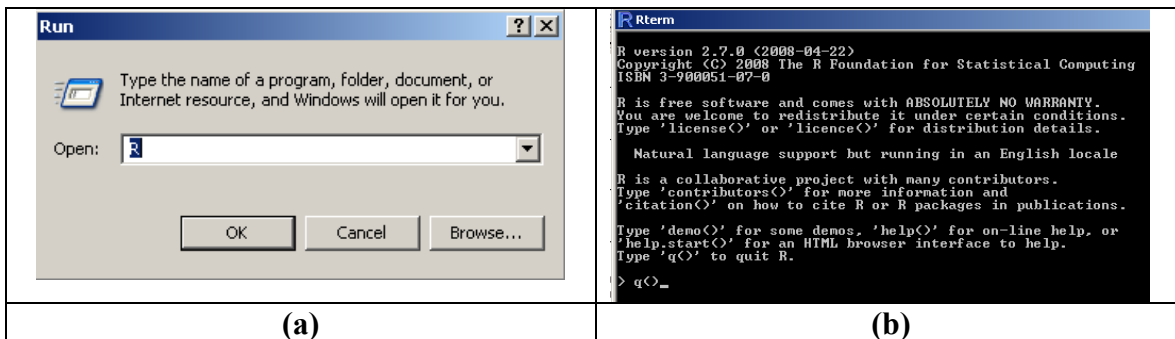
Figure 7.3. R may be invoked similarly to Python. After launching R via Run, you may exit the program by typing "q()".

- -

Do not do the same workaround operation for R as you did for Python.

7.2   Using the ALLTEM Package in Oasis

The folder *survey* located in the release contains an ALLTEM survey that is used in this tutorial. You should be able to follow the tutorial using these files. The survey is an older survey of the Yuma Calibration Grid. The data are old and noisy, but they form a good testing of the processing software. New data should be less of a challenge.

7.2.1   Starting a New Project

Begin by copying the *Survey* folder of this release somewhere you would like to work on it. Now instantiate Oasis montaj in the usual way and start a new project under **File → Project → New** within the same folder the survey data files are located. Figure shows this dialog box.
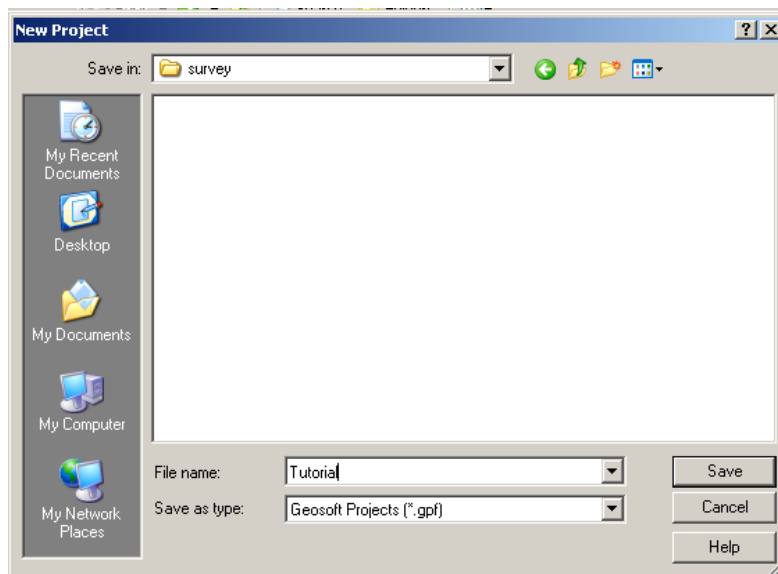
Figure 7.4. Create new project dialog. This one is called 'Tutorial'.

Loading toolbars for a new survey

Once the project is created the ALLTEM toolbar needs to be loaded in Oasis so that you can find the dropdown menus. To do this either:

1) In the **GX** menu select **Load Menu**. If you have placed *alltem.omn* in the *omn* folder of Oasis, this will be one of the menus available. Select this file and press **open**. You will then see a new menu item called **ALLTEM**. I will refer to items in this menu using the arrow convention. You will have to do this every time you process a new survey.

2) If you would like the **ALLTEM** menu to be loaded by default each time you start a new project, making the Load Menu step above unnecessary, open the file Oasis *montaj\omn\coremenus.omn* with a text editor. You should see something similar to Figure . At about line 309 there will be a heading called **Other menus**. Append this list of menus with the line:

```
LOADMENU     "alltem.smn"
```

And the ALLTEM menu will be loaded by default each time you start up. You may automatically load any *smn* menu file in this fashion. For UXO work it may be helpful to load the following as well:

```
LOADMENU ux1-DataPreparation.smn
LOADMENU ux2-ParameterDetermination.smn
LOADMENU ux3-TargetManagement.smn
```
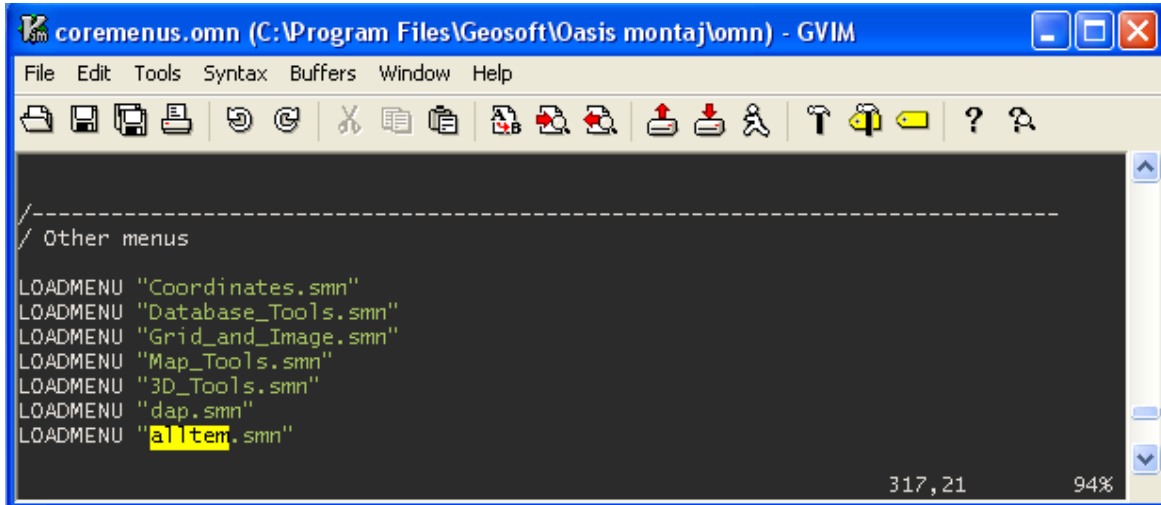

Figure 7.5. The oasis file coremenus.omn. Appending "Other menus" with "alltem.smn" will cause this menu to be loaded by default.

7.2.2   The ALLTEM Menu

Upon successful loading of the **ALLTEM** menu, you should see "ALLTEM" in the main program menubar. The ALLTEM menu (Figure) features 5 submenus: **Survey**, **Noise Characterisation**[1], **Target Selection**, **Inversion**, and **Classification**.

The **Survey** sub-menu contains gxs that allow a field survey to be preprocessed, loaded into Oasis montaj as gdb files and gridded.

The **Noise Characterisation** sub-menu contains several gxs that window a specific area of the survey for noise analysis, or load noise analysis files generated in another survey. The target and patch picking algorithms are statistically based and need this information.

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[1] The Oasis montaj software suite follows British spelling conventions. For consistency items within the ALLTEM suite do as well.
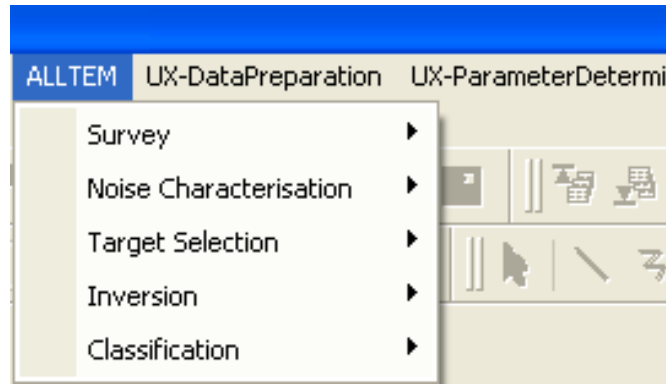
Figure 7.6. The main ALLTEM menu contains 5 submenus as shown.

The **Target Selection** sub-menu contains gxs that pick the locations of targets within a gridded survey and significant patches of data around these targets.

The **Inversion** sub-menu calls an external program that solves the inverse-problem for each selected patch.

The **Classification** sub-menu prepares the data to be passed to a neural network which classifies targets and generates a dig-list.

Each of these menus are discussed in detail in the following sections.

7.2.3   Survey Submenu

The Survey Submenu if further broken into four categories: Preprocessing, Load Survey, Mask Line(s) and Grid Survey as shown in Figure .
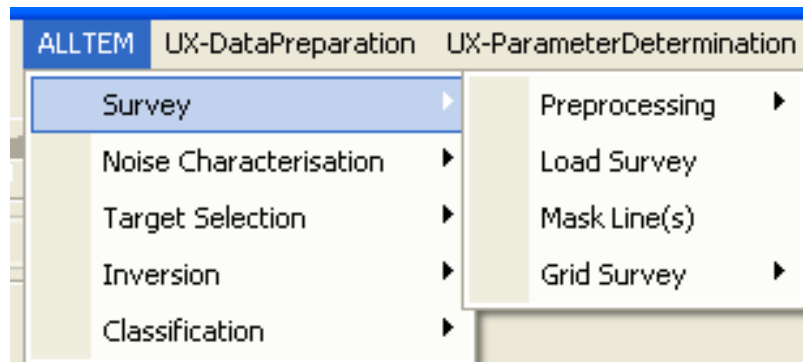
Figure 7.7. The Survey submenu.

7.2.2.1.1   Preprocessing

To date, there is only one gx in the **Preprocessing** menu called **DC Correction**. Some older ALLTEM surveys have huge DC biases on some lines and polarizations. This gx removes most

of these features. Hopefully newer data will rarely need to use this feature. The example dataset, however, does. To use it select **ALLTEM → Preprocessing → DC Correction** as shown in Figure .
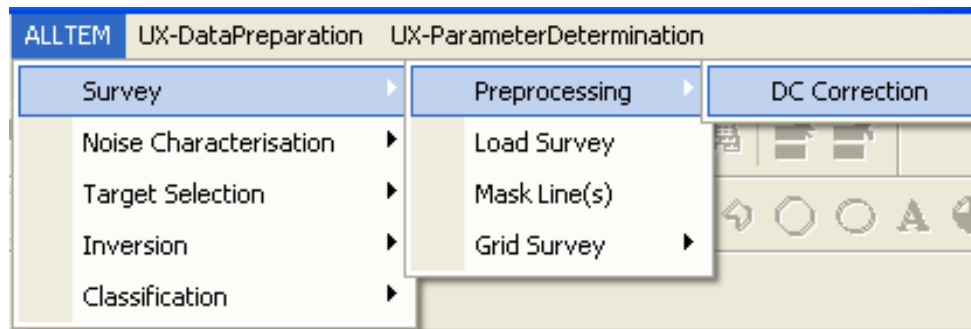
Figure 7.8. DC Correction menu item.

Once you have selected this option the dialog box in Figure opens prompting for a zzm polarity dat (CalGrd2_STDc_zzm.dat) file and an early and late time to subtract and correct. This gx creates a new channel in the survey called

DC${Early Time}M${Late Time}

For the example dataset this channel is called 45M513. **This gx does not in any way change the voltages of the actual time gates in the survey.**
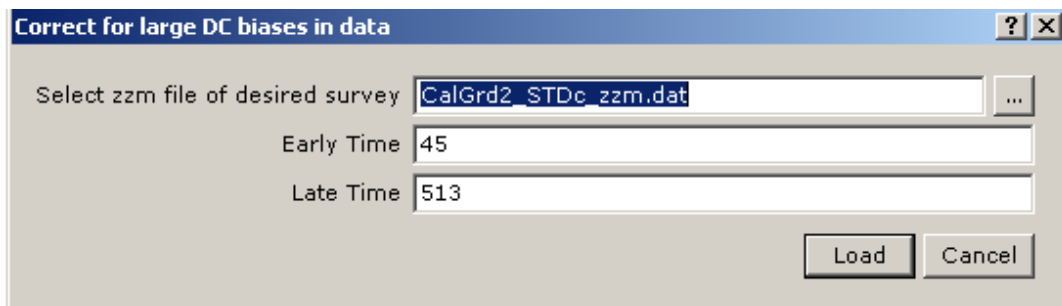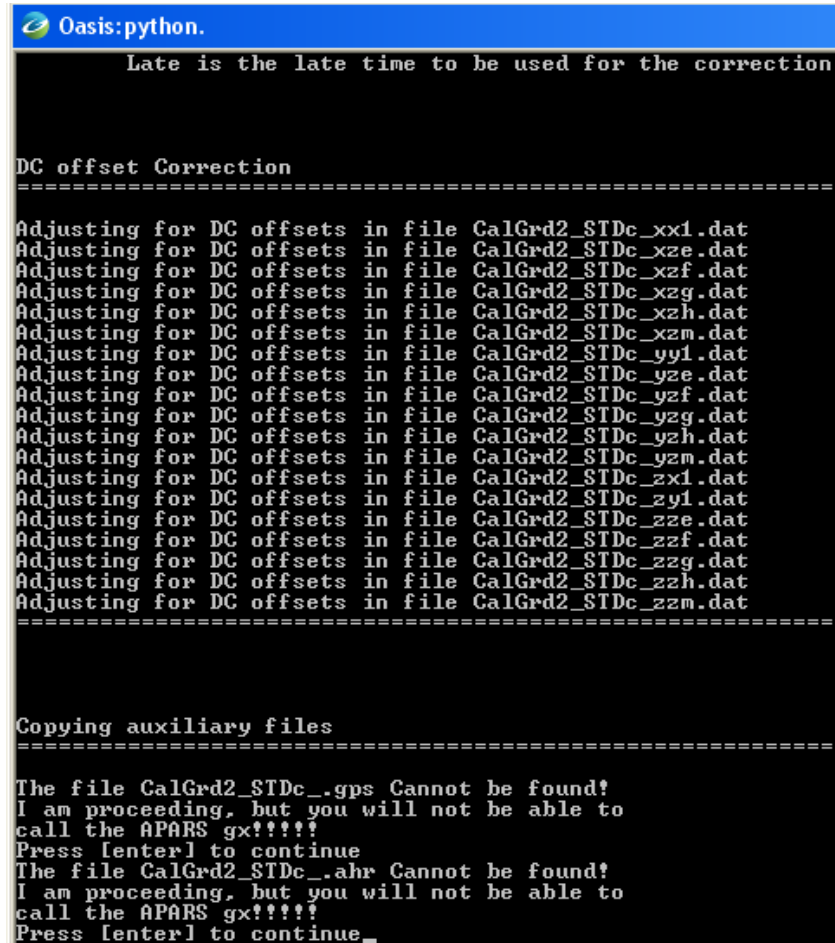
Figure 7.9. DC bias correction dialog box. Select an early and late time to fix.

The DC correction gx is calling an external Python script, O*asis Montaj\usr\ALLTEMDIR\ALLTEM_DC_CORRECT.py*. It is hoped that newer data will not have this problem, so little effort went into the performance of this program. The process may take several minutes to complete. Figure shows the script running. The outputs of the script are new files data called "AdjDC----------XXX.dat", where the dashes represent the survey name. In the case of the tutorial data a new set of files are generated called AdjDCCalGrd2_STDc_XXX.dat. The script also automatically copies each of the auxiliary files (*.ahr*, *.gps*, *.tmr*) from the input data name to match the new name. All of the original files remain unchanged. The tutorial dataset does not contain these auxiliary files as they were not

part of the system when the data were collected. The program will warn you that the APARS executable will not be able to be evoked.

Figure 7.10. Terminal output of the DC Correction program. The tutorial dataset does not contain auxiliary files and a warning is expected.

No data is altered using this gx, rather the new subtracted channel has been corrected. This channel will not be passed onto the inversion.
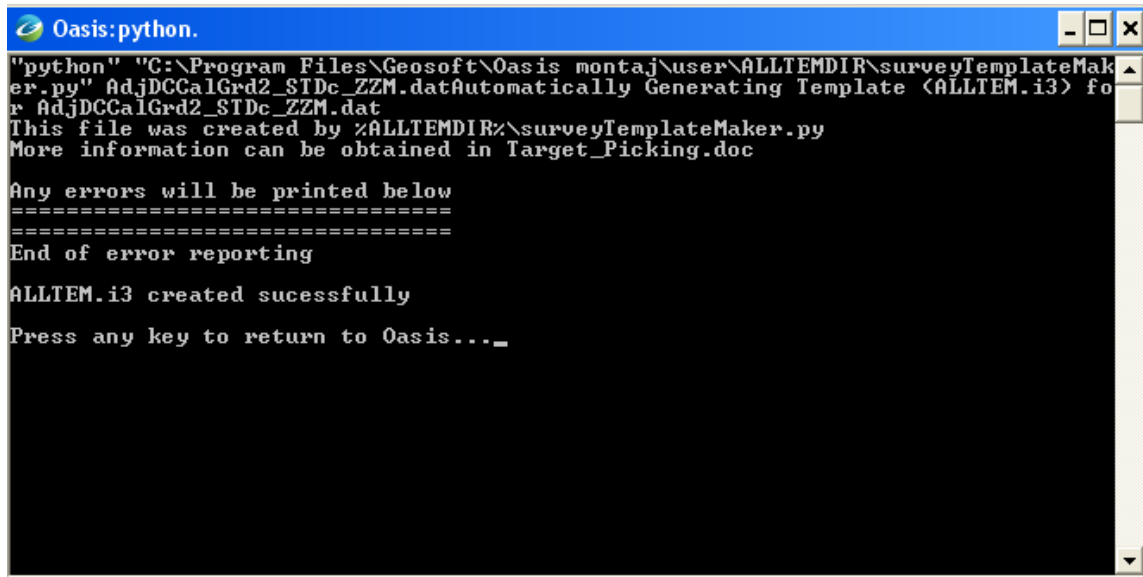
7.2.3.2   Load Survey

To import data select **ALLTEM → Survey → Load Survey**. This will cause the dialog box shown in Figure to be displayed. You must enter the name of the **ZZM** polarization file of the survey you would like to load. Find and select *AdjDCCalgrd2_STDc_zzm.dat*, this may be done using the GUI file finder by pressing the button with an ellipse on it. You can then select which polarizations you would like to process. The program will default to processing all polarizations. For this tutorial, load all 19 polarizations. Press **Load** to proceed. A python script is run that creates an import wizard appropriate for this dataset, each time gate will be appropriately labeled based on header values. The output of this script is shown in a pop-up terminal window (Figure). This script is located at *ALLTEMDIR\surveyTemplateMaker.py*. The template maker can

import standard survey data, adjusted DC data, or test stand data whose formats are outlined in Table . Additions of any other data columns will likely cause errors in either the import or a later gx. These data standards have been agreed to by all parties involved and should be adhered to.

Table 7-1 Acceptable data formats for importing into Oasis program. The timer channel is not explicitly labeled.

Standard	`Line   Rec#   Northing    Easting NonFerrPk   0       7 … (timer)`					
DC Adjusted	`Line   Rec#   Northing    Easting NonFerrPk   0       7      …     DC (timer)`					
Test Stand	`Line   Rec#   Northing    Easting NonFerrPk   Depth 0       7 …`					

Figure 7.11. Output of template maker telling the user that the template has been created successfully.

Occasionally, either the preprocessing software or GPS acquisition hardware has been known to insert unrealistic data with positions many thousand of kilometers away from the rest of the survey. They example dataset contains such features. A dialog box will appear asking about spatially filtering the data. This dialog is shown in Figure . If you answer **yes** to this dialog box any data whose positions are beyond **Survey size** away from the center of the data will be disregarded. You can typically get away using very large values for **Survey size**. For the example dataset, the defaults are fine.

The target picking algorithm is based on the peakedness of subtracted time gates. An early time gate is subtracted by all subsequent times. The dialog box shown in Figure allows you to set which early time gate you would like to use. Generally speaking we have had good luck using time gate 45. Note that if you did the preprocessing step, you may also use the subtracted, corrected channel for analysis and the selection of an early time gate here is not important.
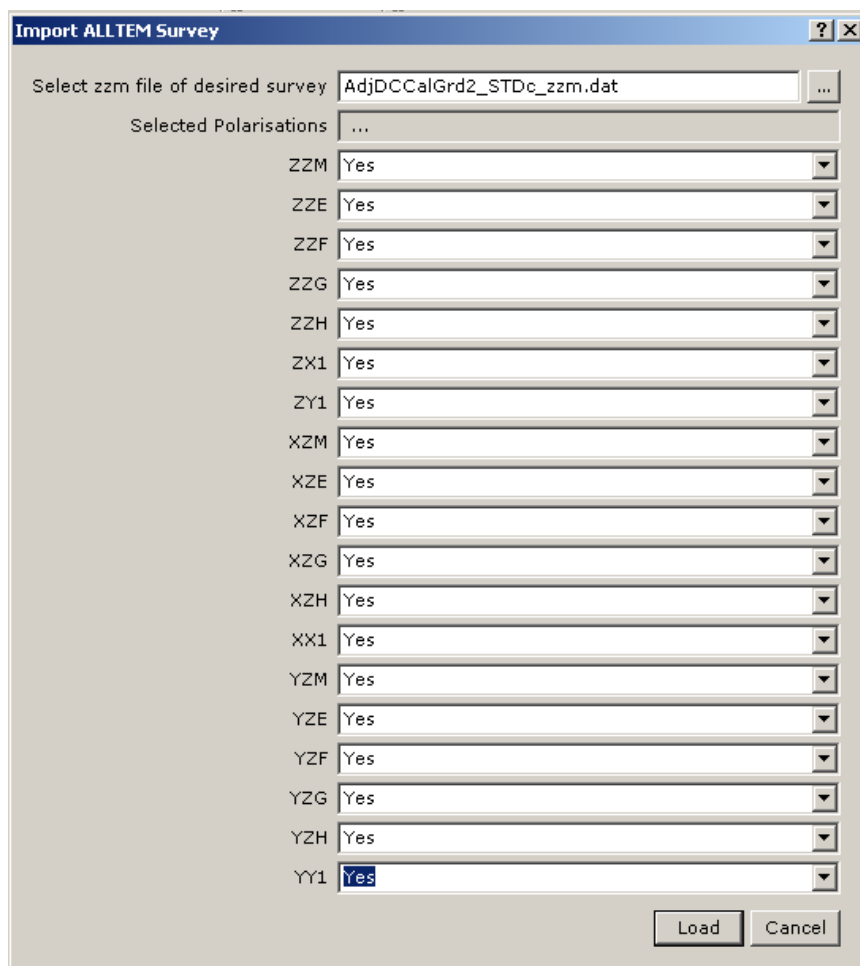
Figure 7.12. Import file dialogue box.
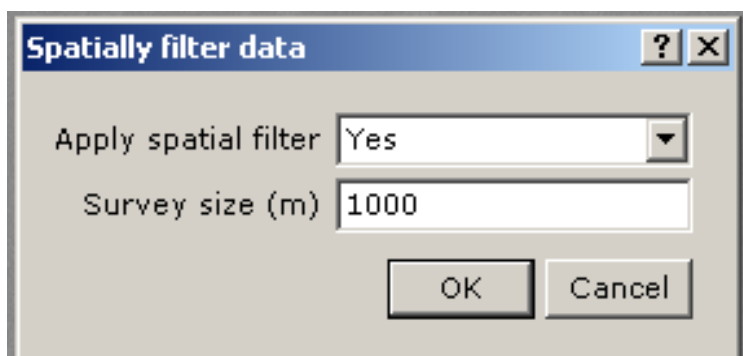
Figure 7.13. Spatial filter dialog.
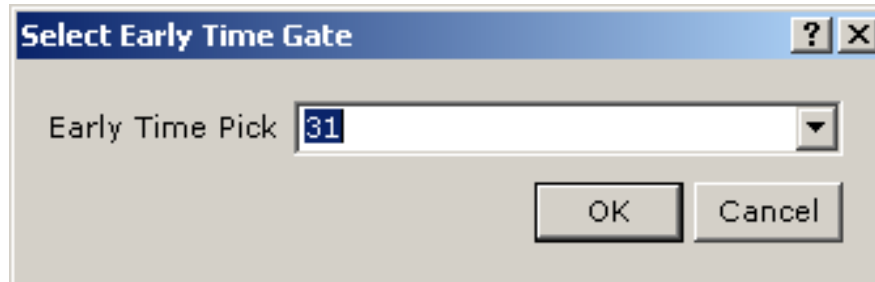
Figure 7.14. Dialog box querying for early time pick.

A preliminary sensor offset correction is then applied to the data. You will be prompted by the dialog box shown in Figure . The front to back offset is the distance from the GPS unit to the center of the cube along the length of the tractor yoke. The left to right offset distance is the sideways offset of the GPS sensor relative to the center of the cube. The small coil offset is the distances from the center of the cube to the center of the small receive coils. This correction is necessary so that grids tie together well when adjacent lines are run in opposite directions. The default values are appropriate for the Generation 1 cart. For version 1 of the cart, the values of 1.43, 0.35 and 0.25 are appropriate. For newer data using Version 2 of the cart the default values of 1.441, 0.0, 0.25 should be used.
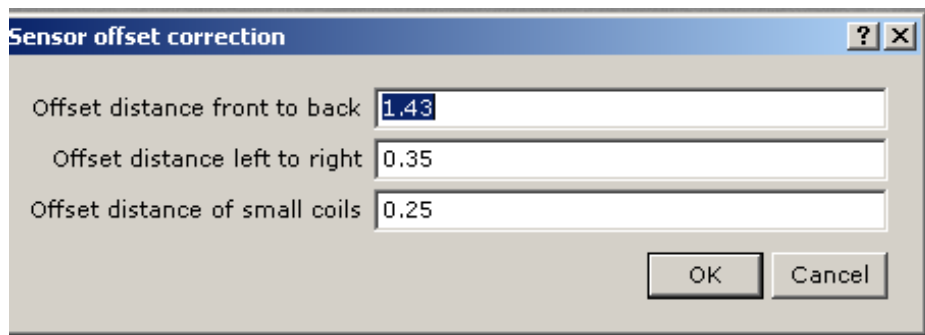
Figure 7.15. Sensor offset dialog box

If you loaded all 19 polarizations of the example database, applied the spatial filter, and used 45 as your early time gate your Oasis workspace should contain 20 databases, one for each polarization and another called *Polarities* which contains information about the survey that other gxs will use. The polarities database has the format shown in Table 7-2.

Table 7-2. Format of the Polarites.gdb database. The number 0.0 represents a file not to process and a 1.0 represents files that will be processed.

Line:0	Pols	Fname
0.0	1.0	FileName_xxx.dat
0.0	1.0	FileName_xxx.dat
…	…	…

The **Pols** column tells other gxs what channels to process. If you decide against using a channel for a specific gx, you may change 1.0 to 0.0.

A map of the survey geometry (*Survey.map*) will be created and left open (Figure). The map may be interactively zoomed in on to see irregularities in line paths. This information will be useful if you are planning on masking lines.
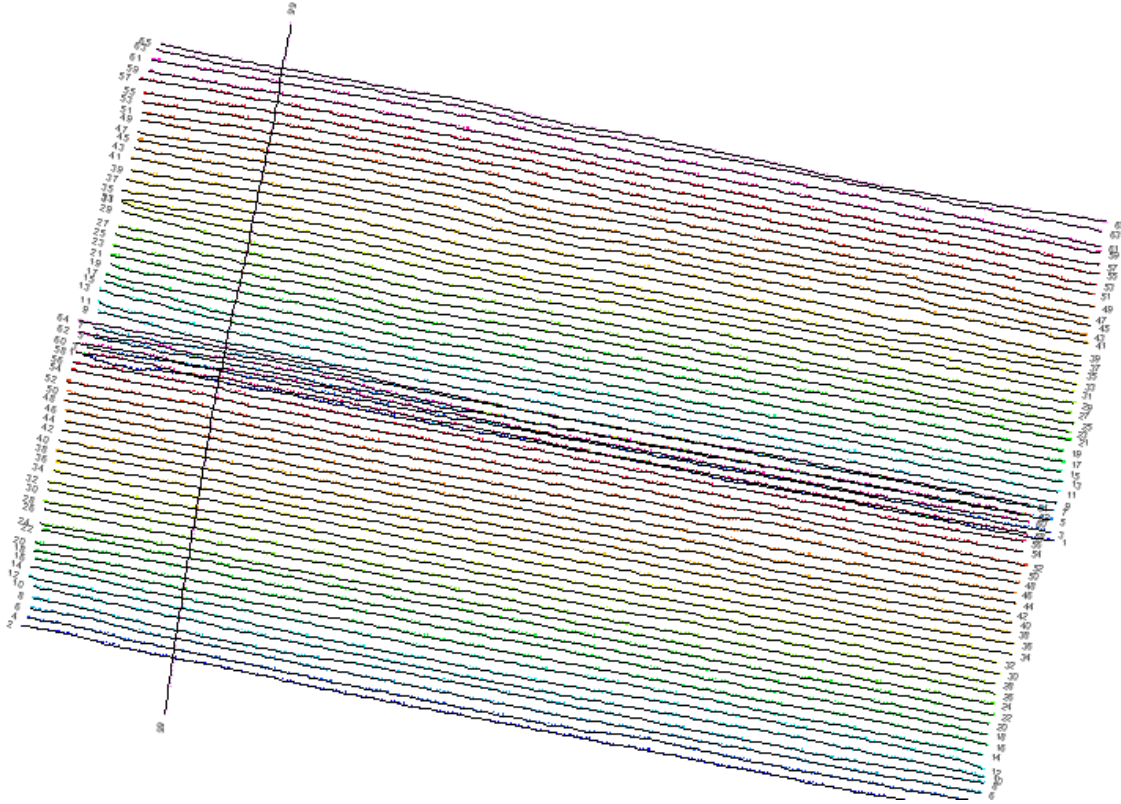
Figure 7.16. Survey.map file created upon import of a new survey.

7.2.3.3 Masking Line(s)

Due to the racetrack survey configuration typically used for ALLTEM surveys, there are generally overlapping lines in an ALLTEM survey. This is shown in
Figure where several lines were taken on top of each other. Additionally tie lines are also taken across the survey. These overlapping lines can cause issues with the inversion algorithm as well as the target patch selection algorithm and should be masked. Using the *Survey.map* image you should find the lines to be masked, and then use the menu item **ALLTEM→ Survey→Mask Line(s)**. This will cause a dialog box asking for a comma delimited list of lines which will not be gridded or passed on to the inversion. This dialog is shown in Figure . For the example dataset lines 1,3,5,7,65, and 66 are masked.

| (a) | (b) |
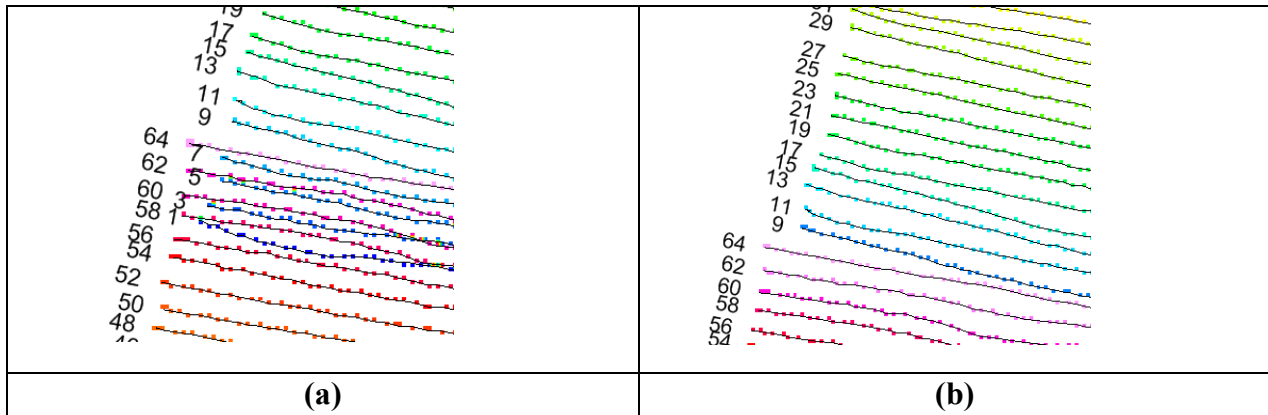
Figure 7.17. Example of overlapping lines in the data (a). Upon masking lines 1,3,5,7, 65, and 66 the survey path looks like (b).

You may run this gx more than once to remove lines, but once they are removed the data are no longer available and the masking action may not be undone without re-importing the data. After running this gx the Survey.map image will be updated, displaying the non-masked survey lines.
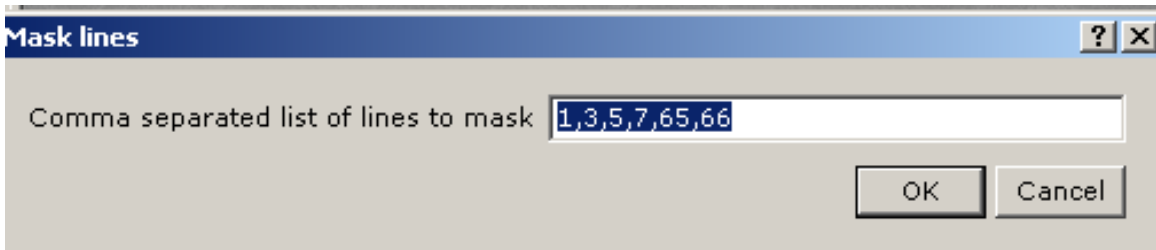
Figure 7.18. Mask lines dialog box.

7.2.3.4   Gridding Data

Once you have imported and masked the necessary lines, you are ready grid the data and begin analysis. Selecting the menu item **ALLTEM →Survey → Grid Survey→ Minimum Curvature** results in the dialog box shown in Figure . Generally speaking you will grid the early time pick (made on import) with one of the latest times. However, if you needed to perform the DC offset correction that channel should be gridded. In our case we elect to grid that channel which is called DC45M513. The channel you grid will determine what channel is used for the rest of the analysis as only a single channel is used for the remainder of the analysis. Newer data can use an earlier time gate than 45.
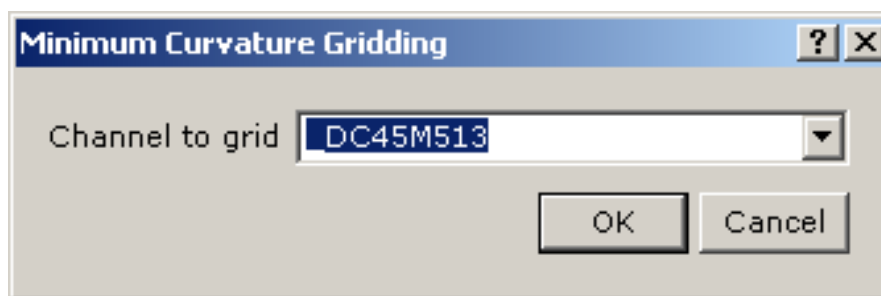
Figure 7.19. Dialog asking which channel to use for target picking. Typically 45M513 is used, however we grid the DC corrected data here.

The result of gridding will be 19 raw grid files like the ones shown in Figure .
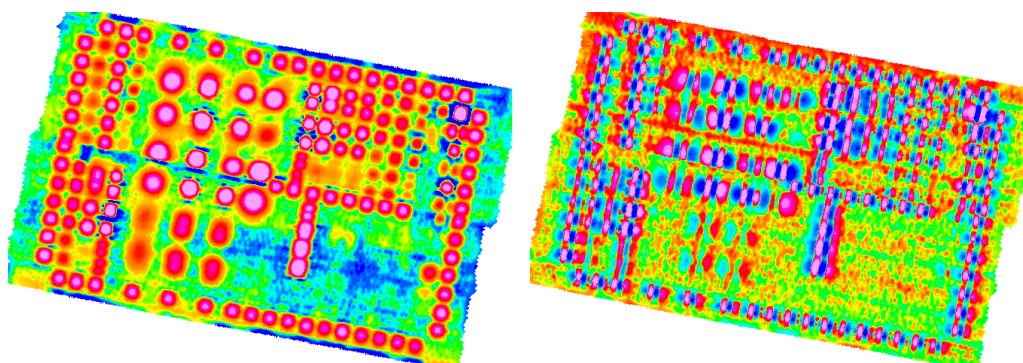
Figure 7.20. Raw grid files. ZZM is shown on left and YY1 on the right.

The over gridding gx listed is called Direct Grid of Data Points. Instead if a continuous grid, it just plots a single data pixel at each data location. It's helpful for QC on target patches (Figure).
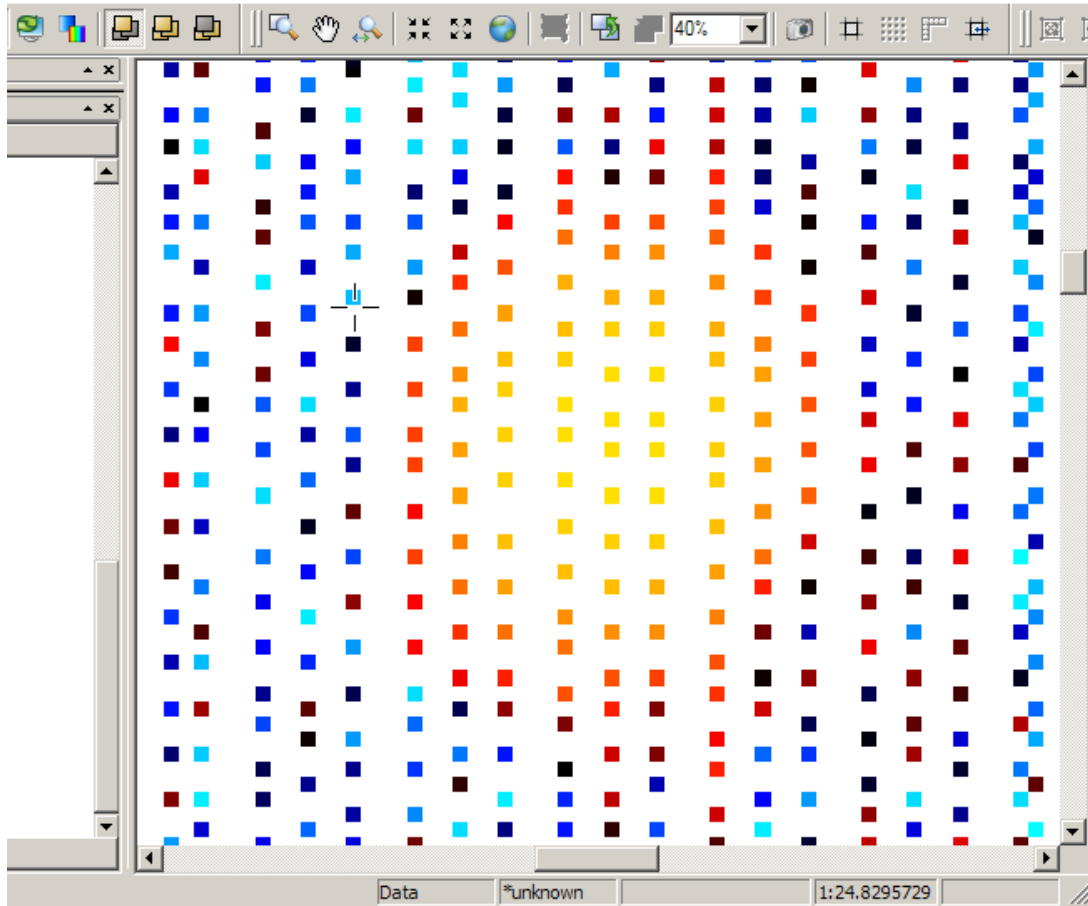
Figure 7.21. Direct gridding of data points, warm colors represent higher amplitudes.

7.2.4   Noise Characterization Submenu

The target picking algorithms are statistically based. To make the algorithms robust against changing conditions or systems it is necessary to define a target free region either in each survey, or in a separate calibration survey where conditions are similar and there are no known targets. The example dataset contains a large target free region, which we will use to define noise levels on each channel. There are four functions within Noise Characterization: **Mask Target Free Area**, **Load Stats File(s)**, **Window Grid(s) Using T-test**, and **Mask Data Using T-test**. They are discussed in that order.

7.2.4.1   Mask Target Free Area

First, find a clean grid channel that you would like to use for picking, ZZM typically works well. Leave this grid open and on top of all others, making this the active grid. The active grid will be bold in the list of grids on the left side of Oasis montaj. Then, go to **ALLTEM → Noise Characterisation → Mask Target Free Area**. You will then be prompted with the dialog box shown in Figure . Click New File and then draw a polygon on the active grid by left clicking the vertices of the polygon. You do not need to close the polygon, this is done automatically. For example a square may be defined with only four points, whereas the last point will automatically

be joined to the first. Right click the mouse and select done to finish drawing the polygon. Once finished you will be asked if that is the polygon you want to use. Say either yes or redraw.
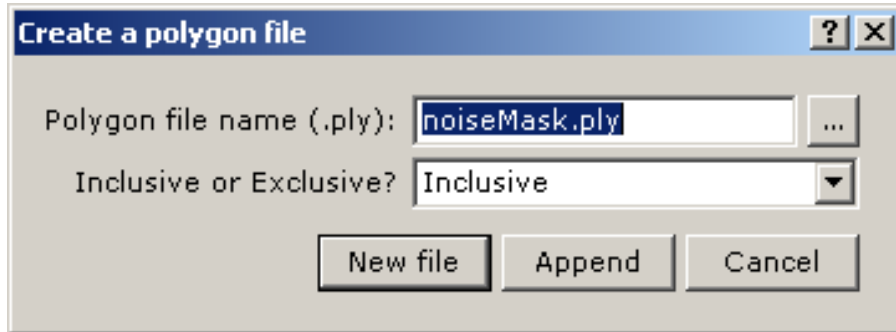
Figure 7.22. Mask Target Free Area dialog box.

At this point 19 csv files are created containing the target free patch data only. These files will be analyzed in R. Two statistical tests will be performed; first a Shapiro-Wilks normality test, and then a t-test for significance. These tests are controlled by two parameters: **alpha** and the **Shapiro-Wilks critical p value.** The critical p-value states how Gaussian the data must appear in order to proceed with the t-test for significance. The p-value is proportional to the probability that the data are from a Gaussian distribution. Note that the p-value is not equal to the probability, only proportional to it.

The noise in ALLTEM can be assumed Gaussian under most circumstances. The exception lies when there are large DC offsets in the data or when different time gates drift at different rates with respect to each other. If either of these occurs the Shapiro-Wilks test will most likely fail and the algorithm attempts to remove outlier lines causing these problems. As a result these stripes are often reported as being significant. System improvements should greatly reduce these striping effects, so this may not be a problem in the future. Progress has been made in a drift correction algorithm that correct for these problems, but it is not ready as of writing. Typical ALLTEM noise looks like that shown in Figure . It can be seen that even the subtracted time gates drift somewhat line to line. The differences in the means between the lines are small however, and this approach still works well. A quantile-quantile plot is shown in Figure . The very linear nature of this plot is strong evidence of normality. Finally, the histogram in Figure is also created from this noise data. The characteristic bell curve of a Gaussian distribution is shown as well as the fit of simulated samples from a 'true' Gaussian distribution with mean and variance equal to that of the noise data. The fit is quite convincing.
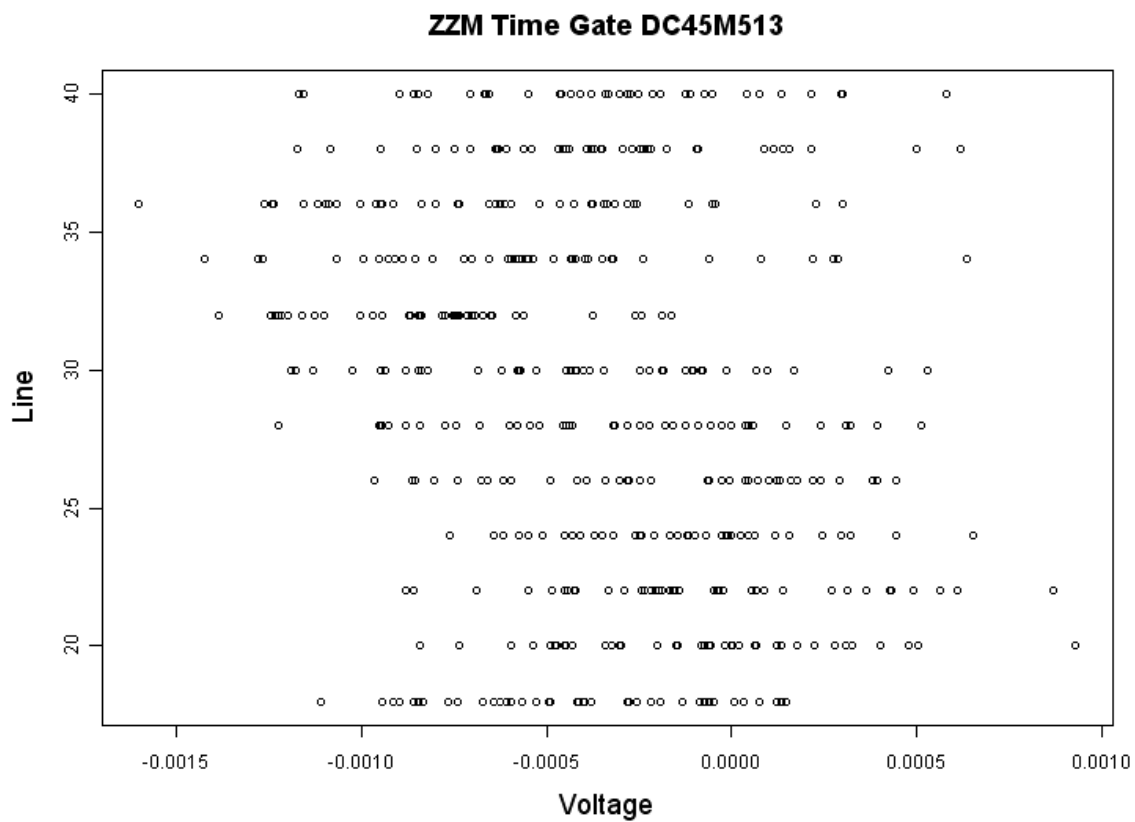
Figure 7.23. ALLTEM noise data for the DC offset corrected channel.
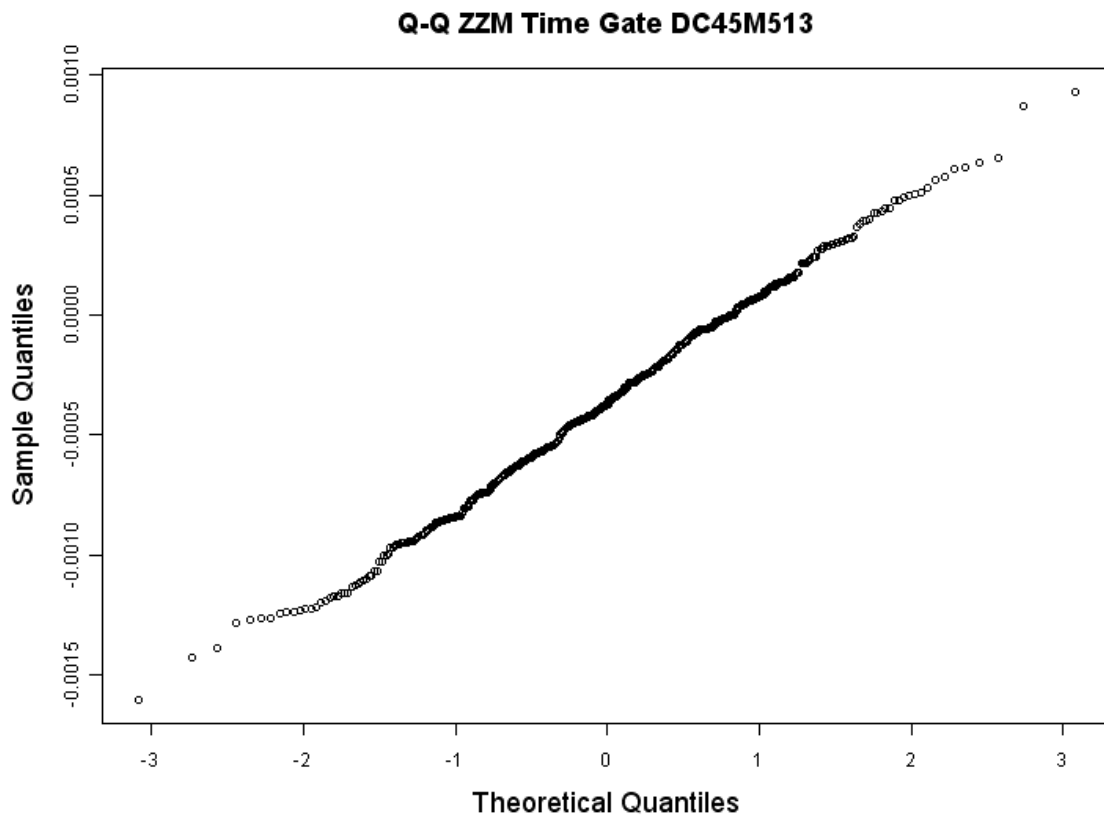
Figure 7.24. Quantile-Quantile plot of the ZZM noise. The linearity of the line is strong evidence of gaussianity.

Target Free ZZM Time Gate DC45M513
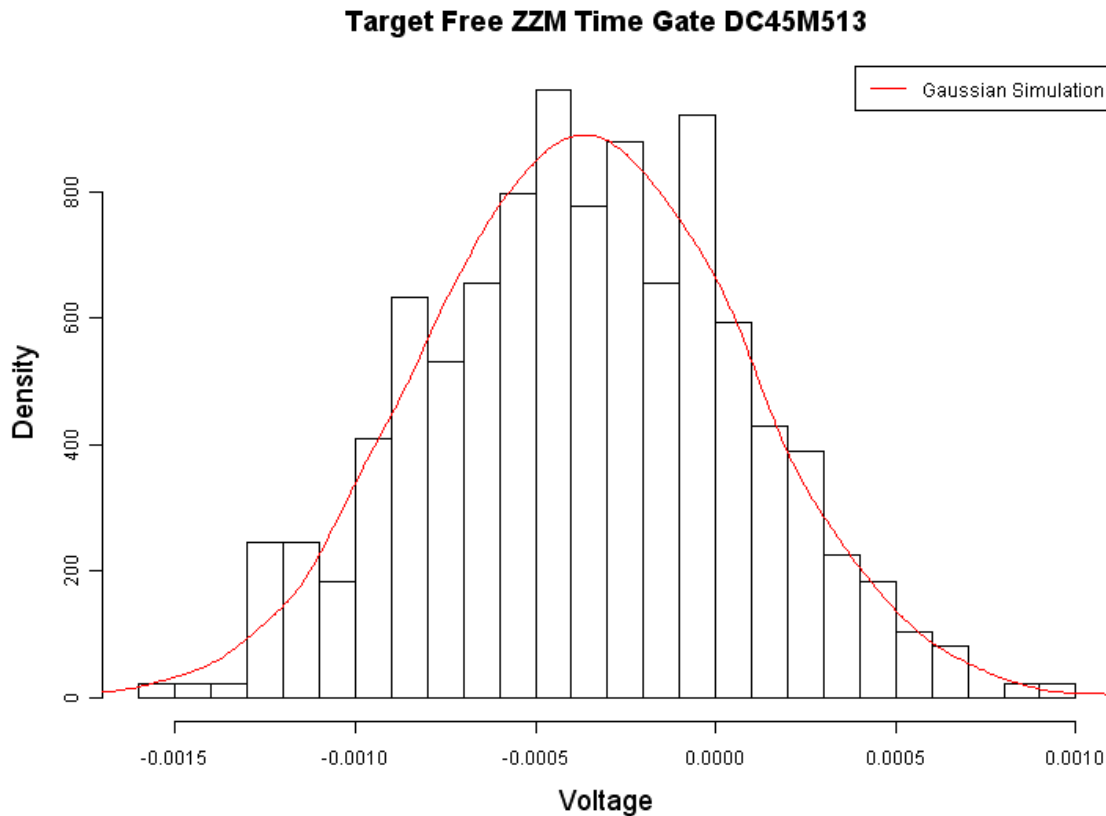
Figure 7.25. Histogram of the ZZM data. The red line represents a simulation of samples from a gaussian distribution of the same mean and standard deviation as the noise data. The fit looks reasonable.

The Shapiro-Wilks test offers a more quantitative measure than the plots shown above. T-tests are rather robust against non-gaussianity and p values from 0.001 and up seem sufficient. The example shown above has a p-value of 0.007. The level alpha (α) defines the significance at which a datum will be classified as either being from the noise distribution or not. For example setting $\alpha=0.1$ means that 10% of the area under the probability density function (pdf) will be defined as being significant. In

Figure the red line is roughly equal to the pdf of that Gaussian distribution. (It is not exactly the pdf as it is based on a simulation.) If $\alpha=0.1$ than 90% of the area under the red curve will be defined as being noise and 5% on each tail will pass the test as being significant, and not from this distribution. It must be remembered that there is a finite probability of any real numeric value coming from this distribution. We cannot state definitively that a datum did not come from this distribution, only that $(1-\alpha)$ percent of the time this datum would not have come from this distribution. How stiff you set this test is up to you.

After the csv files have been created, you will be prompted as to what levels you would like these tests. As stated above a Shapiro-Wilks critical p value of 0.001 seems sufficiently discriminating. Setting $\alpha=0.001$ works well for the example dataset as well. If the drift correction algorithm is completed, or system improvements reduce drift substantially, alpha levels may well

be able to be relaxed in the future. Making alpha larger, say 0.1, will result in larger patches of significant data. The dialog box shown in Figure allows entry of these values.
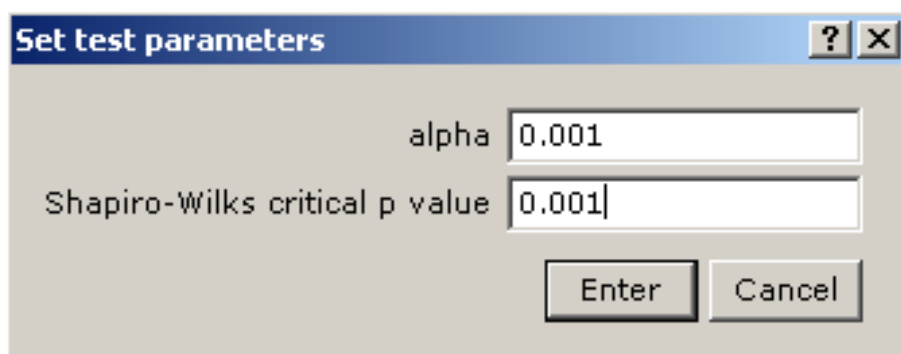
Figure 7.26.   Statistical test dialog box.

At this point statistical tests are performed in R on each of the 19 exported csv files. The csv files are called noise_XXX.csv, where XXX represents an ALLTEM polarization. Figure shows the R program running from within Oasis.
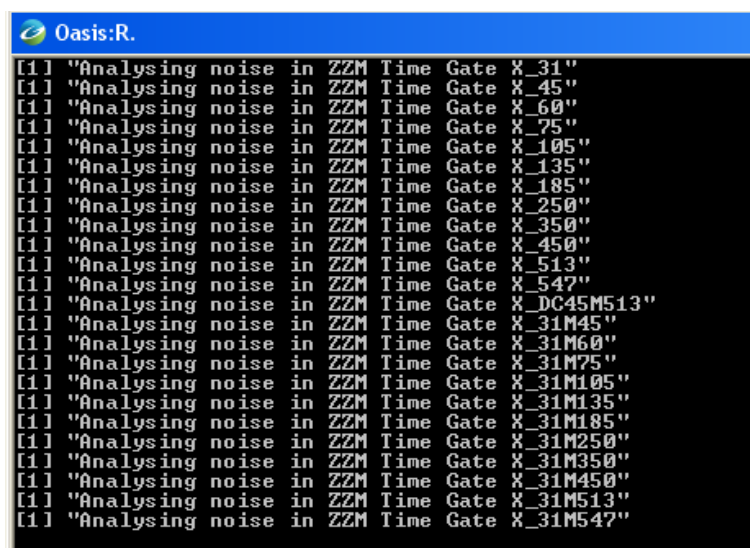
Figure 7.27. R analysis of target free region.

R outputs 19 csv files as well called XXXstats.csv. These have the following format:

	0,	7,	…	31M513	...
Shapiro Wilks p-val	x,	x,	…	x	…
Shapiro Wilks W	x,	x,	…	x	…
Mean Gaussian	x,	x,	…	x	…
Sd Gaussian	x,	x,	…	x	…
T-low	x,	x,	…	x	…
T-High	x,	x,	…	x	…

Where x represents some numeric value, or if the test failed, x may be null. These files are true csv files and do not contain whitespace as shown above, but may be opened easily in excel.

7.2.4.2   Load Stats File(s)

The stat files are automatically loaded by running Mask Target Free Area. However, if you want to use stats files from another survey simply call **ALLTEM → Noise Characterization → Manually Load Stat File(s).** Where you will be prompted to locate a set of stats files you would like to use (Figure). A python script will then generate template whereas these files can be loaded into the current project as GDB files. The output of this python script is shown in Figure .
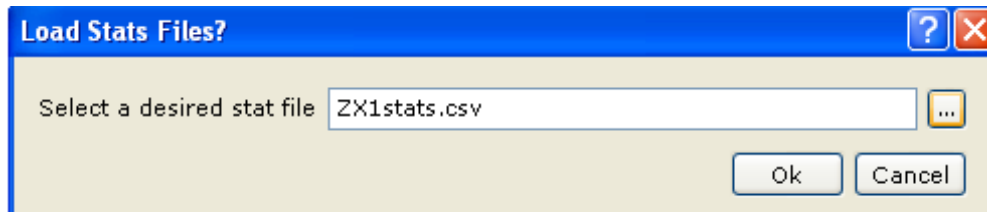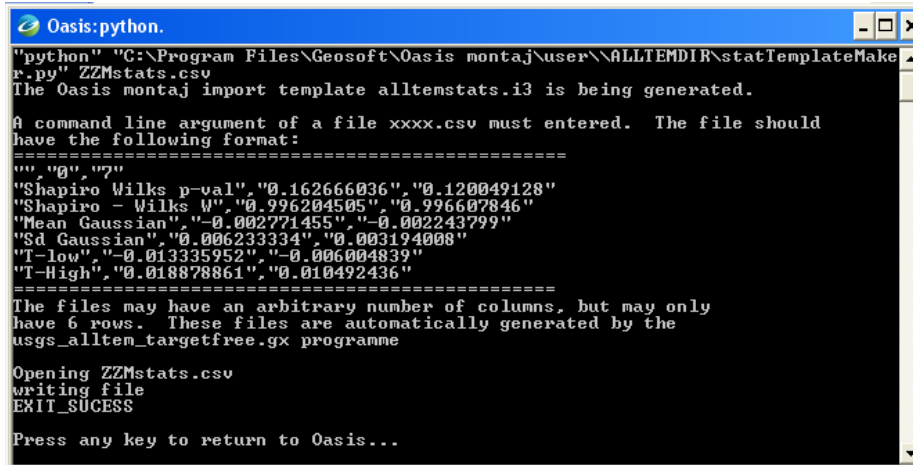
Figure 7.28. Select the stats files you want to load. Use the ellipse button to change directories.

Figure 7.29. Template creation for stats files.

7.2.4.3   Window Grid(s) Using T-Test

This gx creates windowed grids based on the test parameters you defined previously. It is here for quality control and actually plays no role in target picking. Still it is a good idea to run the gx to make sure your test parameters are masking almost all the noise, without also blocking targets. Just click **ALLTEM → Noise Characterisation → Window Grid(s) Using T-test**. The result will be 19 grid files called *AdjDCCalGrd2_STDc_XXX_Wind.grd*.

These grid files show you all the significant data (**At that alpha level**). You should be suspicious of linear or splotchy features that do not look like they are due to target response. This dataset is particularly noisy with several strange lines. Some channels are quite clean like ZZM and ZZH (Figure and Figure) while others are clearly poorer quality (Figure Figure). In particular the 'F' receive and 'X' drive channels seem suspect in this dataset.
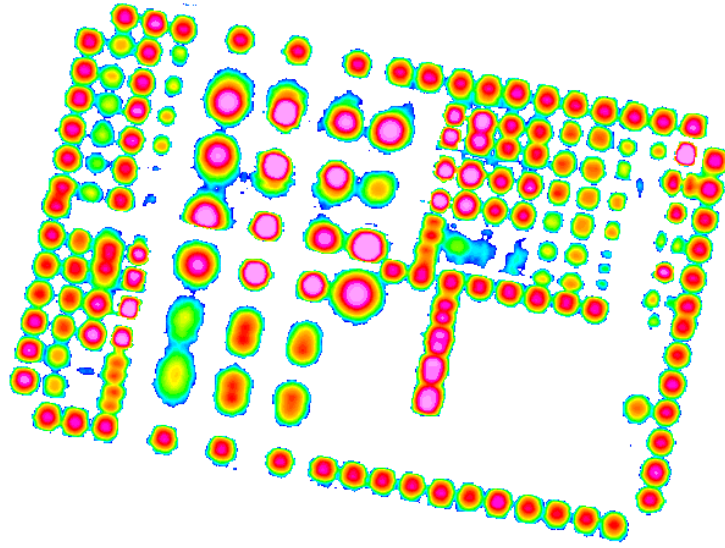
Figure 7.30. Window ZZM, statistically significant data are shown. This is a very clean channel.
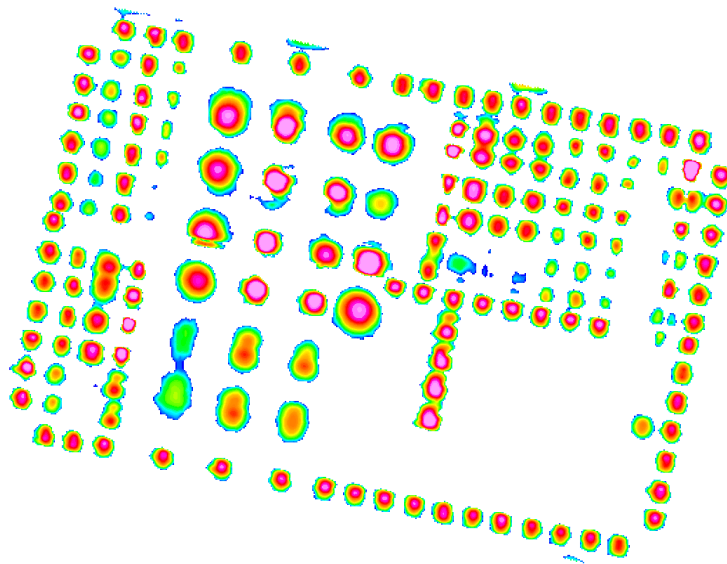
Figure 7.31. Window ZZH, statistically significant data are shown. This is also a very clean channel.
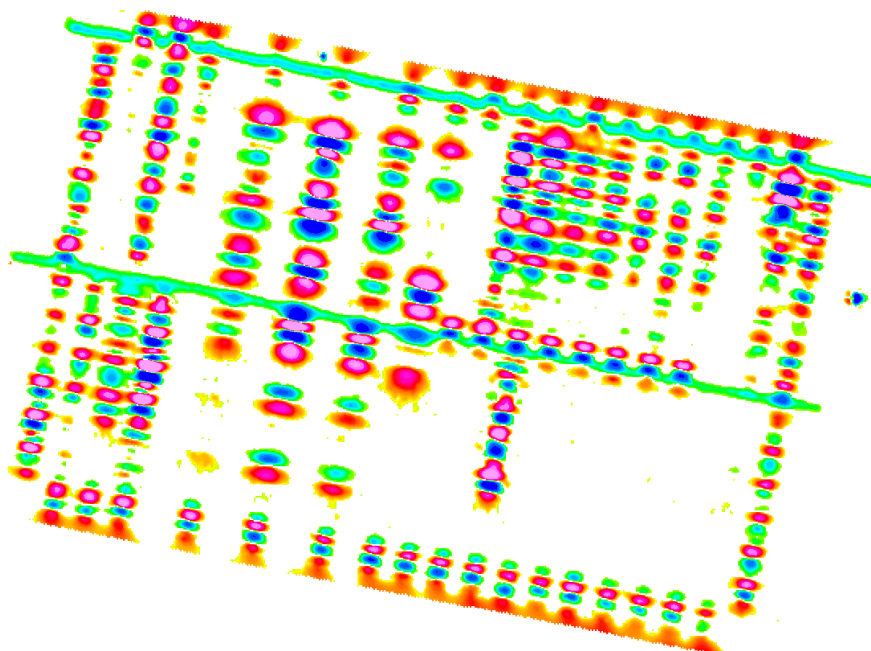
Figure 7.32. Window XX1, statistically significant data are shown. Notice the striping artifacts, that can cause issues with the patch generator.
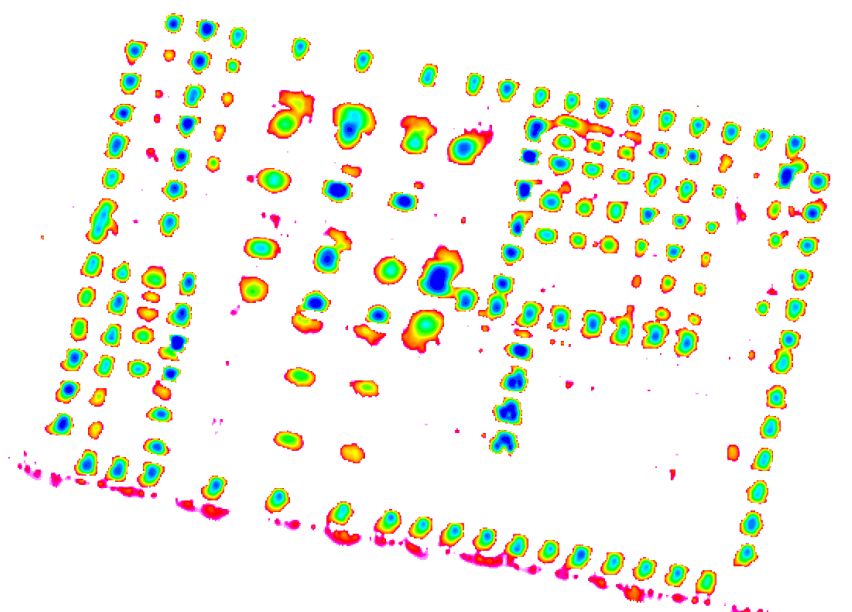
Figure 7.33. Window XZF, statistically significant data are shown. Notice the smaller patches of significant data on this lower signal higher noise channel.
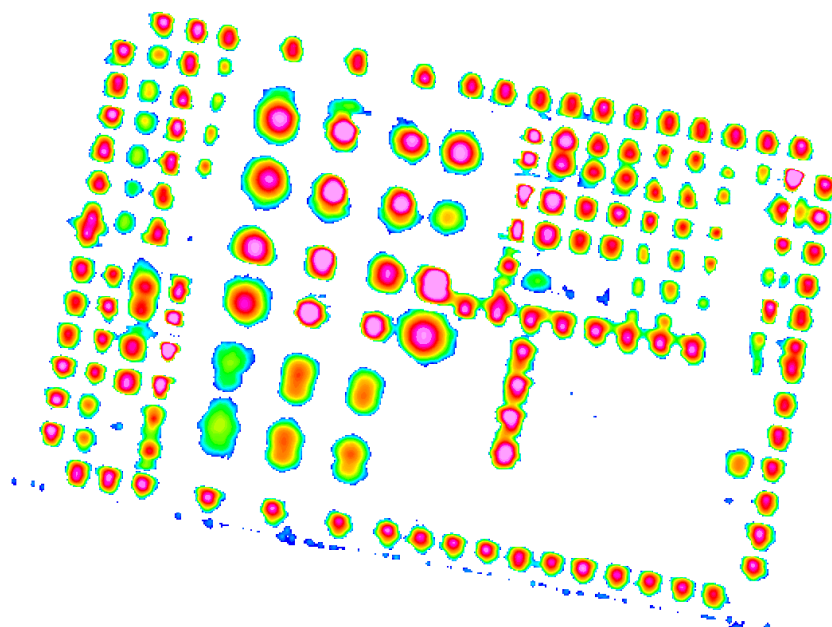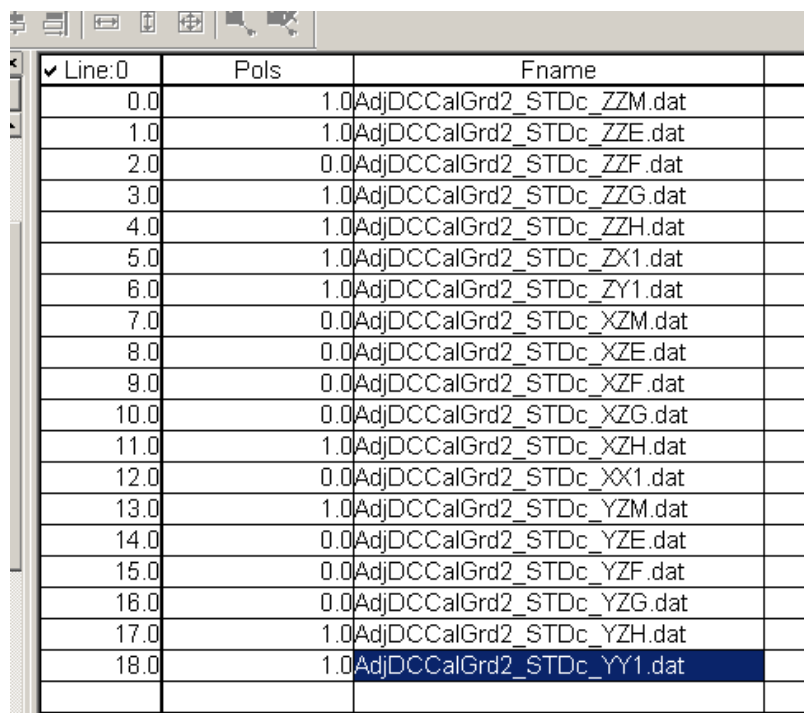
Figure 7.34. ZZF Window. Statistically significant data are shown.

Since we have plenty of clean channels, we should not use these suspect channels to target pick. To do this open your Polarities.gdb database and change the 1.0 values corresponding to our bad channels to 0.0. In Figure I decided not to use zzf, yzg, yzf, yze, xzm, xzg, xzf, xze, and xx1. This seems like a lot of channels, but we are still using 10. Close and save Polarities.gdb. At this point it is helpful to right click on the grids icon on the left side of Oasis montaj and select remove all grids. You can then run **ALLTEM → Survey → Grid Survey** again to see only your selected channels.

✔ Line:0	Pols	Fname
0.0	1.0	AdjDCCalGrd2_STDc_ZZM.dat
1.0	1.0	AdjDCCalGrd2_STDc_ZZE.dat
2.0	0.0	AdjDCCalGrd2_STDc_ZZF.dat
3.0	1.0	AdjDCCalGrd2_STDc_ZZG.dat
4.0	1.0	AdjDCCalGrd2_STDc_ZZH.dat
5.0	1.0	AdjDCCalGrd2_STDc_ZX1.dat
6.0	1.0	AdjDCCalGrd2_STDc_ZY1.dat
7.0	0.0	AdjDCCalGrd2_STDc_XZM.dat
8.0	0.0	AdjDCCalGrd2_STDc_XZE.dat
9.0	0.0	AdjDCCalGrd2_STDc_XZF.dat
10.0	0.0	AdjDCCalGrd2_STDc_XZG.dat
11.0	1.0	AdjDCCalGrd2_STDc_XZH.dat
12.0	0.0	AdjDCCalGrd2_STDc_XX1.dat
13.0	1.0	AdjDCCalGrd2_STDc_YZM.dat
14.0	0.0	AdjDCCalGrd2_STDc_YZE.dat
15.0	0.0	AdjDCCalGrd2_STDc_YZF.dat
16.0	0.0	AdjDCCalGrd2_STDc_YZG.dat
17.0	1.0	AdjDCCalGrd2_STDc_YZH.dat
18.0	1.0	AdjDCCalGrd2_STDc_YY1.dat

Figure 7.35. Edit which polarities you want to use.

7.2.4.4   Mask Data Using T-test

This gx simply does takes all values of the currently gridded channel and masks all values considered to be in the noise to the expected (mean value) of the distribution. It effectively does the same thing as **Window Grid(s)** but instead acts on the data. It only changes the channel which is gridded and will not affect the raw data that will be passed to the inversion. It is a good idea to run this as it reduces the number of targets found in insignificant areas.

7.2.5   Target Selection Submenu

We are now ready for target picking. The simple directions are to call first **ALLTEM → Target Selection → Filter Grids Before Target Picking** and then **ALLTEM → Target Selection → Auto-Pick Targets**.

The **Filter Grids Before Target** picking *gx* is actually a combination of several gx's which discussed in more detail below. All of these gx's are automatically called in the call to **Filter Grids Before Target Picking**.

7.2.5.1   Analytic Signal

The target picking algorithm used is the Blakely test which is based on the peakedness of the data. Peakedness is the fourth moment of the data (mean is first moment, variance is second, and kurtosis is the third). It is a measure of the spikiness of the data. We want to smooth the data enough such that noise spikes and irregularities do not cause a target to be picked. The **Mask Data Using T-test** is a good start to this. We also only want one peak to be present per target, if possible. Most channels will produce only one peak for most targets, but some produce multiple peaks for all targets. An example is YY1 as shown in Figure . To rectify this we perform an analytic signal operation, borrowed from the field of magnetics. These algorithms are really only designed to reduce double humps to single, but we are trying to transform four humps into one. The operation is applied twice to accomplish this. The channels needing this operation are automatically processed, polarizations that produce quadruple humps are processed twice, and those producing double humps are only processed once. The result of performing this on YY1 is shown in Figure .
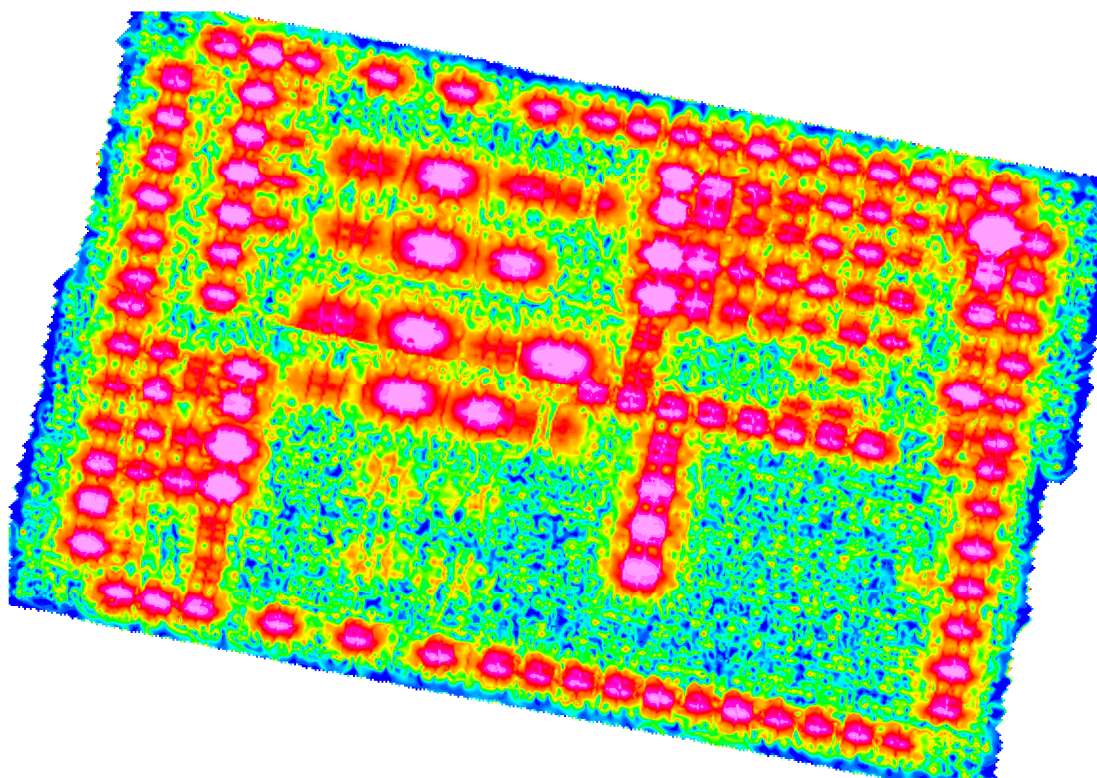
Figure 7.36. YY1 analytic signal.

Gaussian Smooth Analytic Sig Channels

The results of the analytic signal process are better than the input (for target selection anyway) but there are still problems. The data are still rather hummocky and have multiple peaks, which will produce multiple targets per anomalous region. A good fix is to apply a 2D convolution filter using a unit Gaussian kernel (for smoothing).
Figure 7.37.   shows the comparison between a target after analytic signal and Gaussian smoothing.

| (a) Raw YY1 | (b) Analytic Signal | (c) Gaussian Smoothed |
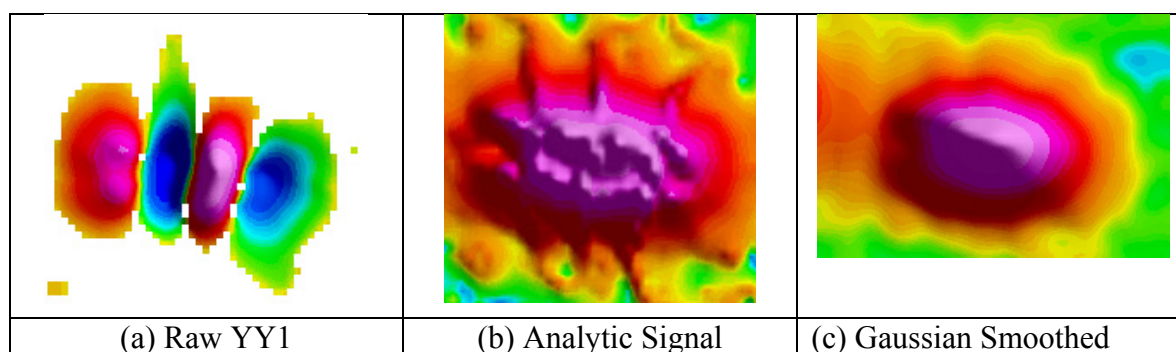
Figure 7.37. The raw data in (a) is converted to (b) via analytic signal, but this will still produce multiple peaks. A Gaussian kernel filter brings this to a more singular peak (c).

Butterworth Filter

We want to smooth the data sufficiently without smearing it too much. A zero order Butterworth filter does this well. The filter is controlled by the file in *Oasis montaj\usr\ALLTEMDIR\zeroOrderButterworth.con*. Higher order filters have far too deleterious effects on the data and are not recommended. If all this smoothing scares you too much, it must be noted that we are acting on the grid image only, and are not affecting the data at all. An example of the output from this filter is shown in below.
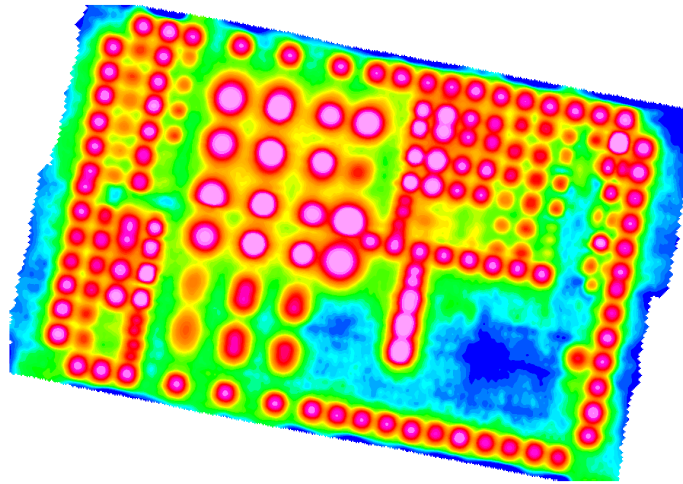
Figure 7.38. Output from the Butterworth filter of the ZZM channel.

Flip Channels With Negative Peaks

The target selection algorithm only picks positive peaks. Some ALLTEM channels produce negative peaks. These should be flipped. This gx does this as shown in **Figure 7.39.** . The gx will only flip those polarities that generally produce negative peaks.

| (a) | (b) |
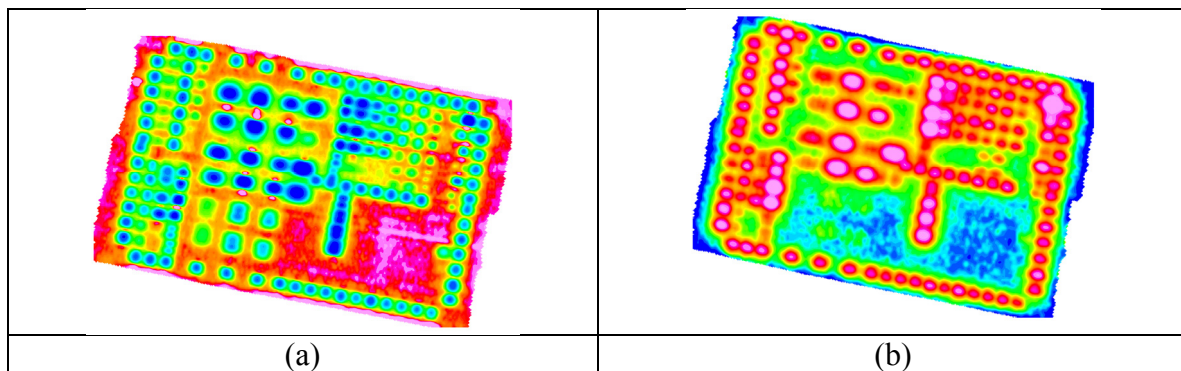
Figure 7.39. Channel before (a) and after flipping (b).

Auto Pick Targets
Now we are finally ready to call the Blakely test. Clicking on this menu item **ALLTEM →**
Target Selection → Auto Pick Targets will cause the dialog box in Figure 7.40.   to appear.

Figure 7.40. Dialog box for Target picking

These numbers define a cutoff value defined by:

$$Cutoff = \mu + linear * \sigma * (1 + \sigma)^{Power}$$

or if an analytic signal has been performed:

$$Cutoff = AnalyticGain(\mu + linear * \sigma * (1 + \sigma)^{Power})$$

Each of the polarities will then produce preliminary target maps of the picks made by that polarity only such as the ZZM polarity shown in Figure 7.41. . If one of these maps is producing many visually obvious false picks, you should consider removing that polarity from the processing queue in the Polarities.gdb file.
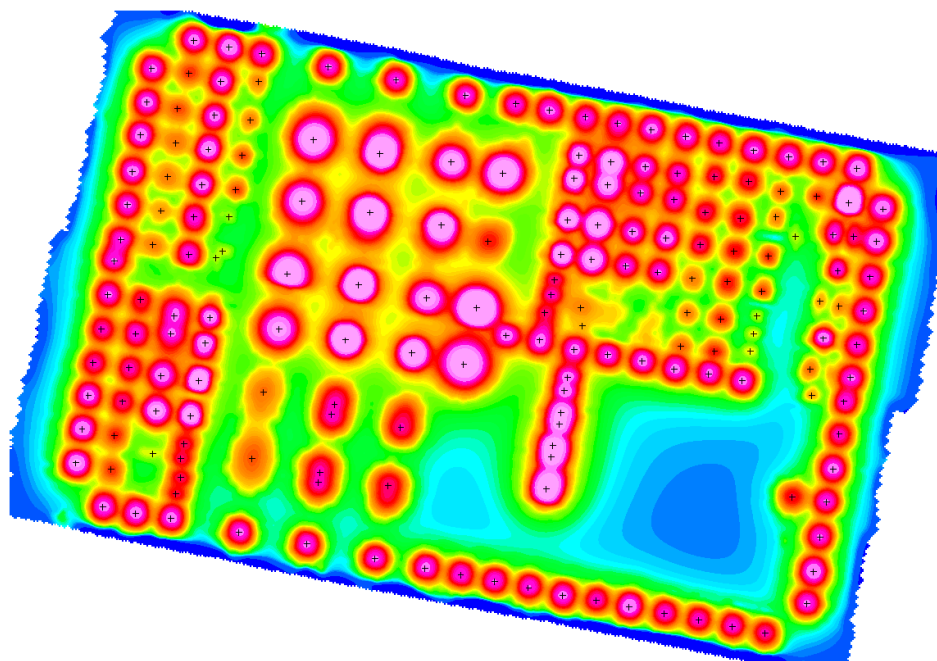
Figure 7.41. Target picks for ZZM

7.2.5.2   Master Target List

To plot all the targets found by all the polarities on a single map select **ALLTEM → Target Selection → Master Map**. This just calls an Oasis UXO function. It should default to the values shown in Figure 7.42. . Make any changes you would like and Click OK. A master target grid similar to Figure 7.43. **Example of i** should be produced.
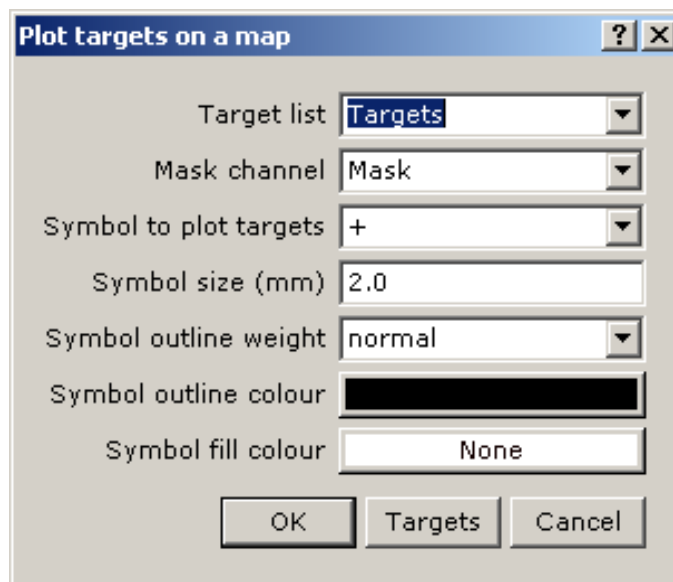
Figure 7.42. Create a master target map.
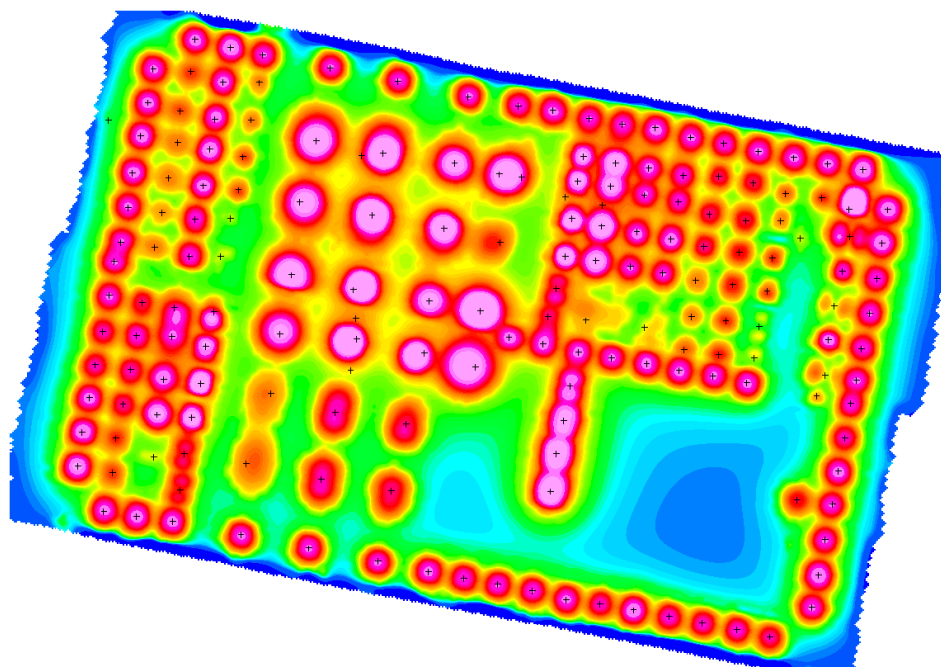
Figure 7.43. Example of initial master target pick grid.

7.2.5.3 Manual Changes

There may be targets on the master target list that you feel are there falsely. For example the furthest left target in Figure 42 has obviously slipped through the cracks. To remove or move targets simply right click on the grid and either select move or remove targets. These functions have pop-up instructions and are quite self explanatory. The same remove target function may be accessed under **ALLTEM → Target Selection → Remove Targets From List**. My lightly edited map is shown in Figure 7.44. .
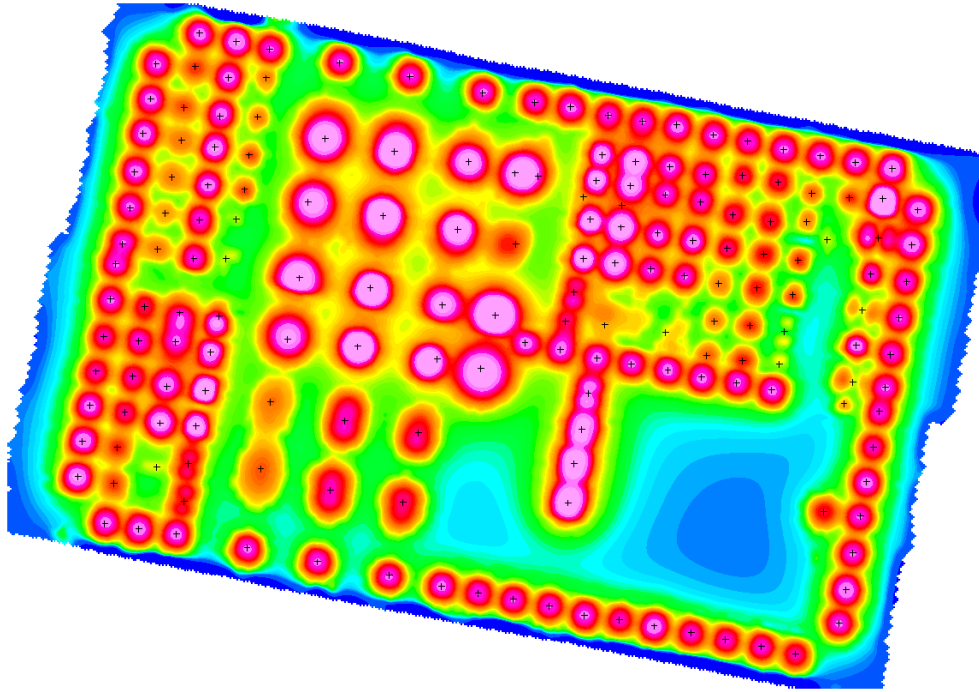
Figure 7.44. Example of final target pick grid.

7.2.5.4   Create Significant Patches

It is now time to extract data near the targets to send to the inversion and classification algorithms. To do this select **ALLTEM → Target Selection → Create Significant Patches**. The patches are drawn based on the t-test, if there are two or more significant datapoints along a survey line, then those points are considered to be truly significant data that will be added to a patch. This requirement was added to reduce the number of noise spikes being added to patches. When you call this gx, the dialog box in **Figure 7.45.** . Most of these fields are self descriptive, Max distance from target means that patches cannot contain data farther away than this from the target point. The minimum patch size makes all patches at least this size, and the patch multiplier just increases the size of all the patches with a linear multiplicitive transformation. The outlier threshold values control a spatial outlier filter. This filter takes the patch position data, and if the kurtosis of the positions is greater than Outlier threshold 2 times the variance of the positions then the data is windowed to contain only positions within Outlier threshold 1 times the variance of the spatial positions. If the data are good quality these values can be set very large and this filter will have no effect.
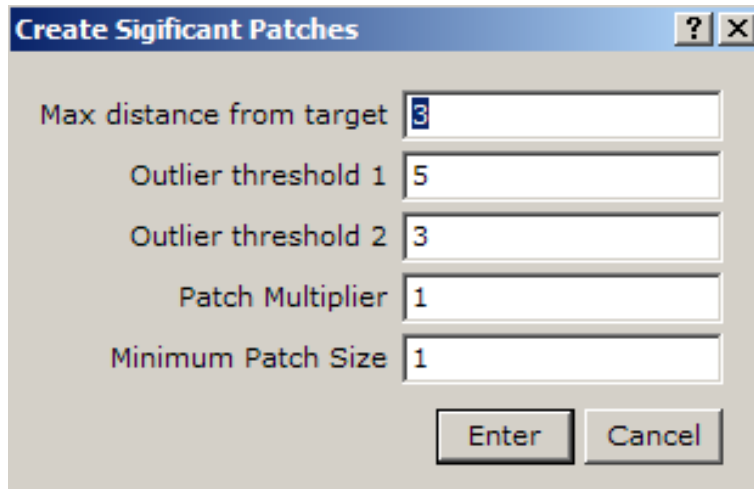
Figure 7.45. Dialog box from Create Significant Patches.

This function acts on the data in the gdb, and not the grid image, although you will see the results on your grids. You may want to regrid the raw data, to see how that compares to the significant patches, as the filtering analytic signal process can make these significant patches seem deceptive. To do this select **ALLTEM → Target Selection → Grid Survey** like before. You may again decide to use different numbers of polarities for this step. Generally noisy channels should be avoided, as the noisy will distort the patches. To do this, just change the 0.0 and 1.0 values in Polarities.gdb (0 is off, 1 is on). This gx takes a significant amount of time for large surveys, as each datapoint is tested and its location tested against the location of all of the targets, to find the nearest target. The ouput of this algorithm, plotted against raw data is shown in **Figure 7.46.** .
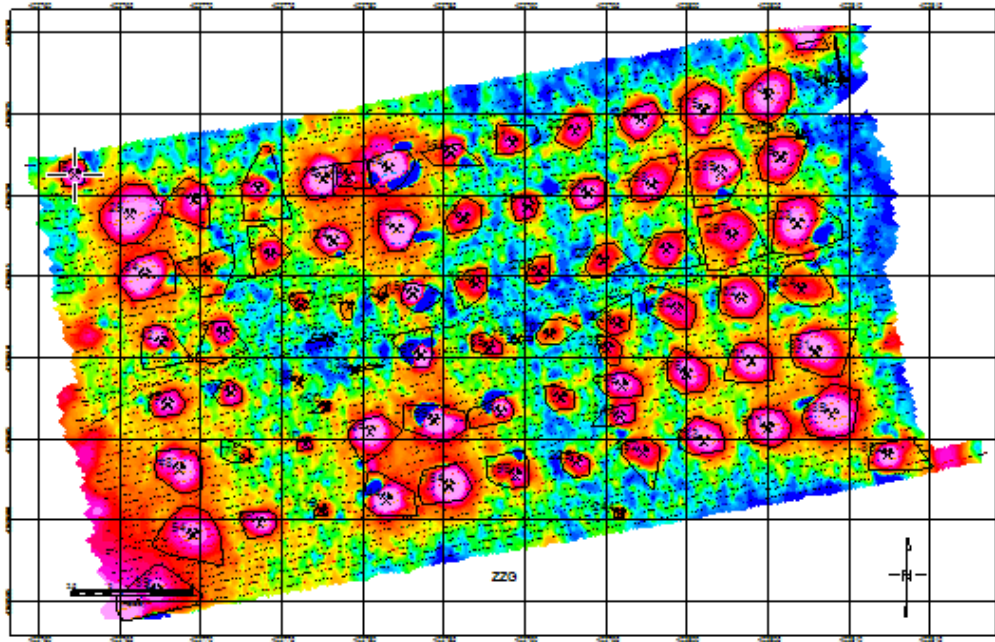
Figure 7.46. Significant patches drawn by Create Significant Patches algorithm, drawn on the raw ZZM data.

The algorithm will create directories for each patch, and fill these directories with the data contained in each patch. The data are in files called XXX_Patch.csv, and are identical in format to the raw data files, but only contain the subset of data in the patch. Additionally these patches will contain two other files initially, `Patch_XXX_ConvexHull.ply` and `patchFreq.txt`. The convex hull just gives the location of the patch points, while `patchFreq.txt` gives the proportional number of datapoints that were used to create the patch. That is, when the algorithm gathers up all the significant data for a patch, what percentage came from each polarity. And example is listed below.

```
Pol        Freq
ZZM        0.327
ZZE        0.158
ZZF        0.178
ZZG        0.158
ZZH        0.17
```

7.2.5.5   Redrawing Patches

Due to changing noise conditions the automatically drawn patches may be obviously wrong. Patches may be manually redraws by calling **ALLTEM → Target Selection → Manually (re)draw patch.** The patch is created exactly like the target free area. Drawing a patch on one polarization updates the patch on all channels.
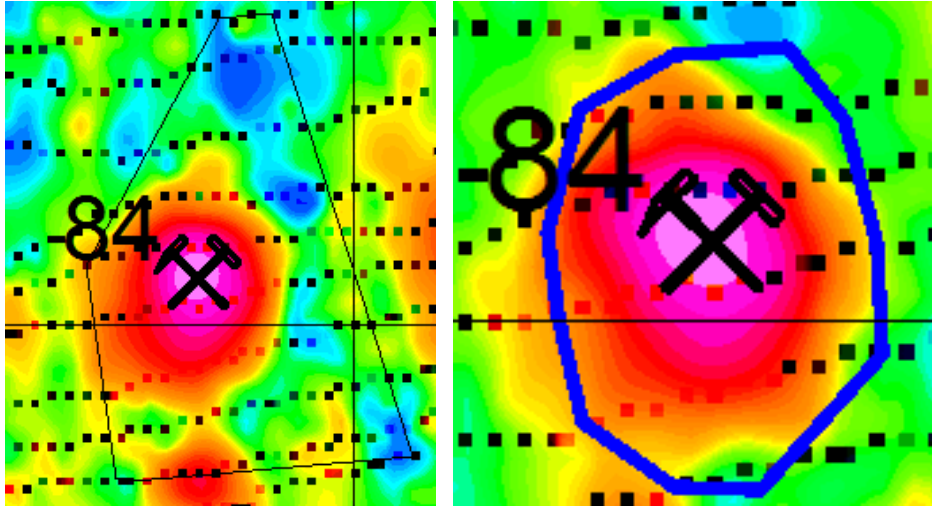
Figure 7.47. Example of redrawing a patch.

7.2.5.6   Determine Patch Properties

To determine properties about each of the patches, run **ALLTEM → Target Selection → Determine Patch Properties**.
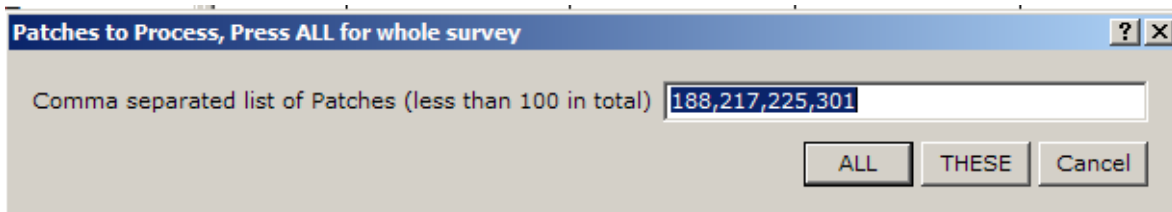
Figure 7.48. Determine patch property dialog box.

For each patch the area is calculated as well as a non-linear curve fitting. The primary output of this program is an ASCII file, Patches.txt, which is of the format:

Patch #	Area	α_1	τ	α_2	k	|Max|	S:N	Ferrous	Path
(int)	(float)	(float)	(float)	(float)	(float)	(Float)	(float)	(string)	(string)
180	1.72	0.951	0.488	0.20	1.071	0.21	0	.00421	d:/raw3Patch_180

There is no header. The area is calculated by making a regular rectilinear mesh grid of the patch area. The area of each cell (fixed and equal) is an editable value. A ray-tracing algorithm then determines which cells are within the patch polygon. If so the area of that cell is added to the total area of the patch. The values of ($\alpha_1, \tau, \alpha_2, k$) are regression parameters based on the nonlinear model:

$$v(t) = \alpha_1 \exp(t\tau) + a_2 t^k$$

Sometimes the power law portion of the model is not seen in the data, and the regression fails. When this happens, a simple exponential (first term only) is fit instead and the returned values of are α_2 and k are 0. The power law fit can be disabled by editing *PatchStats.R*. Plots of these regressions are saved in Rplots.pdf, and an example is shown in Figure 7.49. . A summary of all the regressions for each patch is also saved (**Figure 7.50.**).
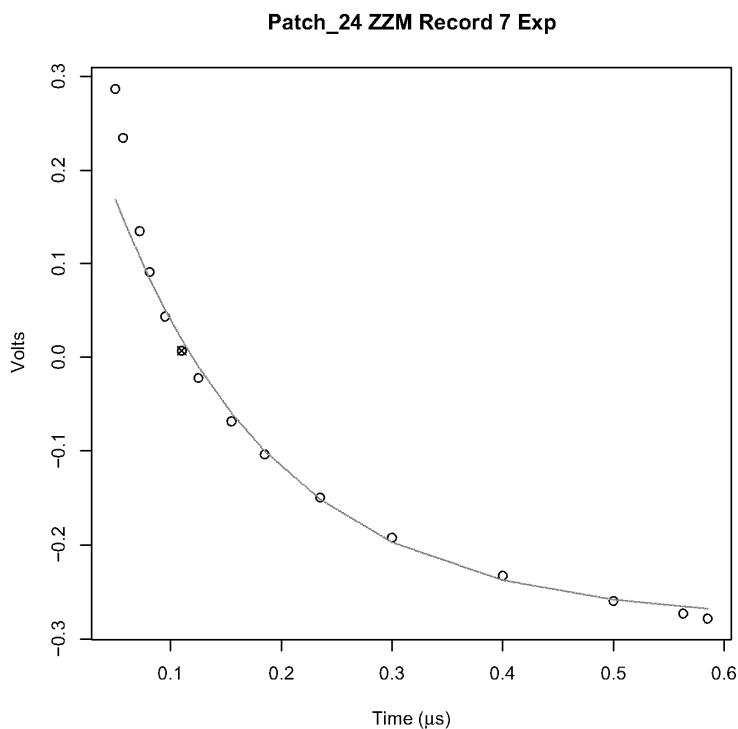
Figure 7.49. Example decay regression plot. These data are fit to a single exponential as ae^{-t}
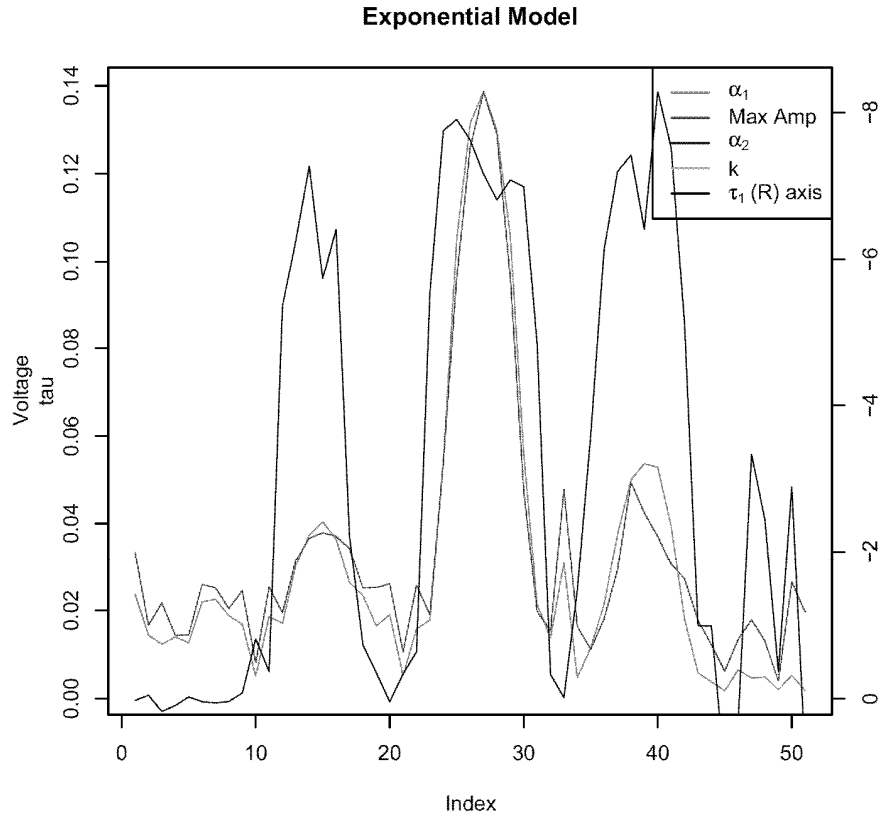
Exponential Model

Figure 7.50. Summary plot of regressions within a patch. The index is just the data record in the patch. It can be seen that the exponential decay time constant is consistent when signal amplitude is high.

The patch analysis is performing regressions (sometimes multiple regressions) on each decay curve in each patch for each polarization. If you are processing every polarization for a large survey this is a lot of regressions and can take some time to do. Details of the regressions can be found in PatchStatsReport.txt. Do not open the pdf file of plots before the process has stopped or, you will cause the program to exit in failure, as it lost write privileges to that file.

A lot of the time this gx consumes is done by Oasis parsing out the individual Patch data files. If you have have only changed a few patches, you can simply perform these operations on those patches by listing them and selecting THESE in the user interface shown in
Figure 7.48. . The Patches.txt file will then only include those patches however, but at times this is useful. Patches.txt is an input to the inversion and APARS algorithms.

Redrawing the patches and looking at the regressions is sometimes an iterative process. If you have run THESE in the dialog box, the PatchStats.txt.

7.2.5.7   APARS

To perform final position refinements on the data simple call **ALLTEM→ Target Selection →Apars**. In order to use this routine gps and ahars data must be present. This functionality is under development.

7.2.6   Inversion Submenu

The physics based inversion takes a single patch of data and inverts for magnetization moments. The Oasis montaj wrapper is set up to run the inversion in a batch process over all of the patches of data. The inversion program is an external executable than can be run independent of Oasis montaj, however.

7.2.6.1   Setup Inversion

Setting up the batch inversion job is as easy as selecting **Inversion → Setup Inversion**. This program copies all the necessary files from the INVERT subdirectory in ALLTEMDIR to each patch directory and prepares for an inversion. If you open up one of the processed directories you will find several executables files as well as modified datafiles, called TARGET.XXX.CSV. These files incorporate the updates from the APARS algorithm. The inversion setup uses Patches.txt as its control file to determine which targets are analyzed with the inversion program.

7.2.6.2   Run Inversion

The next step is calling **Inversion → Run Inversion** which will run the inversion algorithm in a batch mode for each target in their sub-directories. DOS windows will come up for the run in each target subdirectory. The order the inversion is run comes from the listing in Patches.txt.

7.2.6.3   Inversion Results

After each inversion is complete in each subdirectory another small program (ALLTEMRes in the Invert subdirectory in the ALLTEMDIR subdirectory in Oasis Montaj) is called that collects all of the inversion results into two files called *InversionRes.txt* and *InversionRes2.txt*. Each has a slightly different format.

InversionRes.txt, used by the Classification analysis discussed below, has the format:

Northing	Easting	PatchNum	Len	Wid1	Tau
4369578.896	402779.782	5	0.040	0.036	-11.287
4369576.996	402780.159	6	0.039	0.035	-11.729
4369574.944	402780.549	7	0.040	0.034	-12.374

InversionRes2.txt has the same as *InversionRes.txt* plus the orientation information, has the format:

Patch	Northing	Easting	Depth	Azim	Inclin	MSE	Len	Wid1	Tau
5	4369578.896	402779.782	-0.192	87.391	87.677	0.083	0.040	0.036	-11.287
6	4369576.996	402780.159	-0.173	98.163	71.466	0.084	0.039	0.035	-11.729
7	4369574.944	402780.549	-0.168	98.947	87.545	0.080	0.040	0.034	-12.374

The compilation of these two files can also be run post-inversion with the **Inversion →
Inversion Results** selection on the Inversion menu.

7.2.7   Classification Submenu

Inverted data is compared to known inversion parameters, currently Length, Width, and Tau (time-decay constant). Each of these parameters is considered independent of each other. For a given inverted set values (length, width, tau) and a database of known inverted values of the same type the distribution of the known values is compared to the unknown inverted values using traditional statistical tests. However as multiple comparisons are being made, this must be factored into the analysis.

We perform a multiple comparison Studentized T-test on the unknown quantities comparing them to the known inverted values. This test operates off the well known T-distribution, which is similar to a Gaussian distribution with fatter tails. The probability density function of this distribution is:

$$f(x) = Gamma((n+1)/2) / (sqrt(n\ pi)\ Gamma(n/2))\ (1 + x^2/n)^{-((n+1)/2)}$$

Where Gamma is the Gamma function and n are the degrees of freedom. For a given μ_k the intervals that the t-distribution will cover at a given confidence level (α) are computed. These intervals are expanded to account for the multiple comparisons using Bonferroni's method. This is accomplished by $\alpha=\alpha/m$ where m are the number of comparisons being made.

We have a limited inversion database, see Table below, to compare to and it is really unclear as to where in the true distribution we have sampled with our inversions. To account for this a bootstrap technique is used.

This database is contained in the ordnance files ALLTEMDIR\Ordnances. These files contain the format:

```
105mm_M60
len     wid1    tau
0.154  0.050   -6.3586
0.154  0.039   -5.1389
0.148  0.050   -9.4961
0.134  0.044   -9.1316
0.161  0.045   -5.8998
0.138  0.047   -7.2777
```

Where the first line is the name of the ordnance, the second line is a header line and the rest give values. Any new known ordnance information can be added to the database by writing a new file in this directory with this format. Additional columns may be added, but must be done across all database files.

7.2.7.1 Setup Classify Inversion Results

This menu selection sets up the inversion results for classification. The data in the file InversionRes.txt are recompiled from the target subdirectories. The file Patches.txt is used to determine which targets are written to the inversion results file. The Setup Classify batch command creates an Ordnances directory in the Oasis project directory and then copies the data files found in OASIS Montaj\userALLTEMDIR\ORDNANCES into that directory. The R script Classification.R script is also copied into the project directory.

classifySetup.bat
mkdir Ordnances
copy "C:\Program Files\Geosoft\Oasis montaj\user\\ALLTEMDIR\\Classification.R" .
copy "C:\Program Files\Geosoft\Oasis montaj\user\\ALLTEMDIR\\Ordnances" Ordnances\.

7.2.7.2 Classify Inversion Results

This menu selection begins the bootstrap technique that involves simulating data around each set of known values and performing a t-test on this simulated data. This process is repeated many times. The actual number is set in the Classify.R script in ALLTEMDir subdirectory. For instance an inversion is compared to 100 simulations of Len, Wid, Tau for each known target. In total 1700 simulations are performed. For simulations of given known ordnance all positive t-tests are tallied as shown Figure 7.51. This example inversion is classified as likely a 81mm ordnance, over 80 out of 100 simulations were within the α confidence level specified. This bootstrap technique is fairly robust against unknown distributions, but is slower than a simpler test and produces results with lower certainly. A PDF file named ClassificationResults.pdf is created as well as a CSV file named ClassificationResults.CSV

Ordnance 40 likelihood at significance level 0.03725
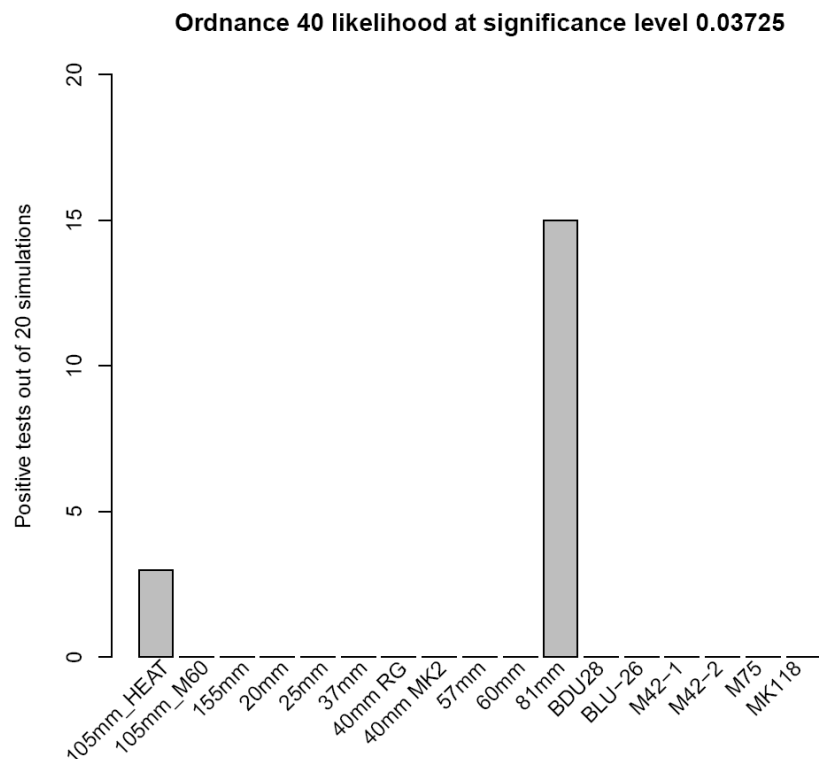
Figure 7.51. Example of classification results for patch 40.

PatchNum	Northing	Easting	MSE	Len	Wid1	tau	PO1	ORD1	PO2	ORD2	CLA
9	3288285	538059	0.128	0.078	0.036	-11.748	NA	NA	NA	NA	Clutter
39	3288279	538064	0.290	0.071	0.029	-8.725	0.60	81mm	0.30	60mm	Can't Say
40	3288295	538064	0.255	0.085	0.031	-9.392	0.75	81mm	0.15	105mm_HEAT	Ordnance
45	3288287	538064	0.149	0.141	0.043	-8.707	0.60	105mm_M60	0.10	155mm	Ordnance
59	3288287	538066	0.172	0.089	0.032	-11.111	0.10	81mm	0.05	105mm_HEAT	Clutter
65	3288294	538066	0.118	0.081	0.031	-10.172	0.30	81mm	0.05	105mm_HEAT	Clutter
68	3288292	538067	0.213	0.102	0.040	-8.485	0.75	81mm	0.45	105mm_M60	Ordnance
74	3288289	538067	0.207	0.073	0.021	-8.027	0.80	60mm	0.45	25mm	Ordnance
82	3288301	538068	0.325	0.095	0.038	-10.789	0.40	105mm_HEAT	0.15	81mm	Clutter
83	3288272	538068	0.272	0.117	0.034	-10.469	0.05	105mm_HEAT	0.05	81mm	Clutter
86	3288280	538068	0.324	0.069	0.031	-10.669	0.20	81mm	0.00	105mm_HEAT	Clutter
101	3288294	538069	0.271	0.069	0.023	-7.937	0.80	60mm	0.30	40mm MK2	Can't Say

Figure 7.52. Example of ClassificationResults.CSV in a tabular format.

7.3   GX Documentation

Implementation details of each gx are reported in this section.

7.3.1   usgs_alltem_import

This GX imports an ALLTEM survey saved in tab delimited ASCII format by the LabView preprocessing software. These files must have the naming convention surveyName_XXX.dat, where XXX is the polarization (ie. zzm, zze). The format of the files must be of the type:

surveyFileXXX.dat must have the following (conventional) format:
===

Line	Rec#	Northing	Easting	0	7	…	(Timer)
		Meters	Meters	Volts @	Volts @	…	ms
1	0	122.21	123.21	0.211	0.452	…	12323123
1	1	123.23	123.21	0.541	0.246	…	12323323

Note: This gx was written to handle up to 100 time gates. If more than this are needed line 71 of the *usgs_alltem_import.gxc* source code will need to be edited. A comment has been placed here directing exactly what to change.

After the files are imported, this gx also performs a few checks on data integrity. First, if the user specifies it spatial outliers are removed. This is a simple algorithm that removes any data that is beyond the entered 'survey size' away from the computed center of the survey. It is effective in removing spatial outliers that are sometimes found in the output files from the preprocessing software. Second, it queries for an early time gate and subtracts this from all subsequent time gates. This early – late subtraction goes against the convention of most ALLTEM processing, but produces more positive valued anomalies which the target picking algorithm prefers. Next, this gx splits a survey on the line numbers and calls **usgs_alltem_uxlag.gx** which performs sensor offset corrections to the data. The **usgs_alltem_import** gx creates the dialog asking for the offset distances. If the default distances need to be changed (such as for the new cart) the *usgs_alltem_import.grc* file will need to be edited (around line 67) and the gx recompiled. After offset corrections have been made, the survey lines are remerged (by calling **mergelines.gx**). The performance of **mergelines.gx** is sub-par. However, making this faster would likely involve writing a non gxc based program (such as in FORTRAN or C), the development time to learn to do this was not available to date. The reason the lines must be split and then remerged is that the **usgs_alltem_uxlag** function will try to tie all lines together if the survey is not split. At later stages it becomes advantageous to split along target patch. You cannot split a survey into multiple groups of lines. A survey map is then created letting the user mask lines.

7.3.2   usgs_alltem_uxlag2

This gx is basically uxlag rewritten to make multiple offset corrections for ALLTEM data. Since the GPS receiver has an offset from the center of the cube in two dimensions, both of these offsets must be accounted for. Additionally, due to the racetrack geometry, if adjacent lines are not run in the same direction, data from the small coils will not tie due to their respective offsets from the center of the cube. This gx corrects for these offsets. A dialog box is called from usgs_alltem_import specifying these offset lengths as discussed above. The raw positions are stored in the X_Raw (Easting) and Y_Raw (Northing) channels. The X_Raw2 and Y_Raw2 are temporary arrays and can be neglected.

7.3.3   usgs_alltem_masklines

This gx simply creates a mask channel "LineMask" and fills it based on a user defined string of lines to mask. A subset of the data is then created that does not include the masked lines. The gx may be run multiple times to remove lines. The masked lines are more deleted than masked, due to the behavior of the **dbsubset** gx, which is being called. If you want to restore masked lines you need to re-import the data.

7.3.4   mergelines

This simple gx merges all lines into a survey onto one, defined by the system parameter, MERGELINES.OUT. A sub-gx that does the opposite of split database on line. The current database will have all Lines merged into one. Note that these are Oasis montaj Lines and are not to be confused with ALLTEM survey lines. Oasis montaj allows for only one level of lines and it is useful at times to have different channels represented as lines. The gx relies heavily on the MergeLine_DU gxc function (created by geosoft) whose performance is lackluster. Slow imports of large surveys are mainly bogged down by this function. It may be worth dedicating some time to make a better solution to merging all lines.

7.3.5   usgs_alltem_rangrid

This gx performs minimum curvature gridding on a single channel; this channel is (solely) used in target picking. Later versions of this gx may grid multiple channels. Other gridding techniques were too slow to be practical.

7.3.6   usgs_alltem_analytic

This gx performs analytic signal calculation of the gridded data on the channels YY1, XX1, XZM, and YZM. If additional channels are desired to be processed the `if' conditional on line 126 of *usgs_alltem_analytic.gxc* should be edited. The gx first performs an absolute value operation of the grid and then does the analytic signal calculation. This gx uses the standard Oasis motaj Analytic signal algorithm.

7.3.7 usgs_alltem_apars

This is a simple call to the binary program located in *ALLTEMDIR\APARS_BIN\apars_vX.exe*. This program performs final cart position refinements based on data recorded by the AHRS instrument. More information on this program is available.

7.3.8 usgs_alltem_butterworth

This gx performs a zero order butterworth filter on the gridded data. It acts on all grids. The filter is controlled by the file in *Geosoft\Oasis montaj\user\ALLTEMDIR\zeroOrderButterworth.con*. The butterworth filter reduces the number of false targets identified by **usgs_alltem_targetpick**, and does a better job than the smoothing filters that the uxdetect package calls standard.

7.3.9 usgs_alltem_dccor

This gx calles the Python script *ALLTEMDIR\ALLTEM_DC_CORRECT.py*. The gx prompts for two time gates, an early and a late. This script subtracts the two time gates and then computes an analytic derivative on the subtracted data. If there are sufficient flat areas of data a mean is computed. This area is expected to have a zero value after subtraction. If this mean is above a threshold value (0.005 volts) the mean of the flat data is subtracted from the whole line. This threshold value may be changed by editing line 155 in *ALLTEMDIR\meanCorr.py*.

7.3.10 usgs_alltem_directgrid

This is a convenience gx that does a direct gridding (places dots at each datapoint only). This can be helpful to check the shape of the final patches which may seem off looking at the gridded data. Often times the gridding algorithm and filtering will distort the shapes of the anomalies causing the patches to appear mis-shaped. The patch creation algorithm works directly off of the data and is not prone to these artifacts.

7.3.11 usgs_alltem_drift

This gx calls an R program that attempts to perform a drift calculation on raw Alltem data in a line by line process. The algorithm is different from the DC correct as it attempts to correct for linear or quadratic drift along a line, rather than a static shift. The R script can be found at *ALLTEMDIR\alltem_drift.R*. The Algorithm first temporarily smoothes the data with an exponential smoother, it then calculates the curvature and analytical derivative at every point along the line. If the derivative and curvature are both acceptably low, the area is considered to be target free and is used on a regression on drift. This regression model is then subtracted from the entire line. ALLTEM time gates do not always drift together as is expected. The cause of this time gate dependant drift is not known, but the `noisy' channels are more prone to this. It could be explained by some sort of electronics malfunction or loose ground. With any luck the new boards will address this problem.
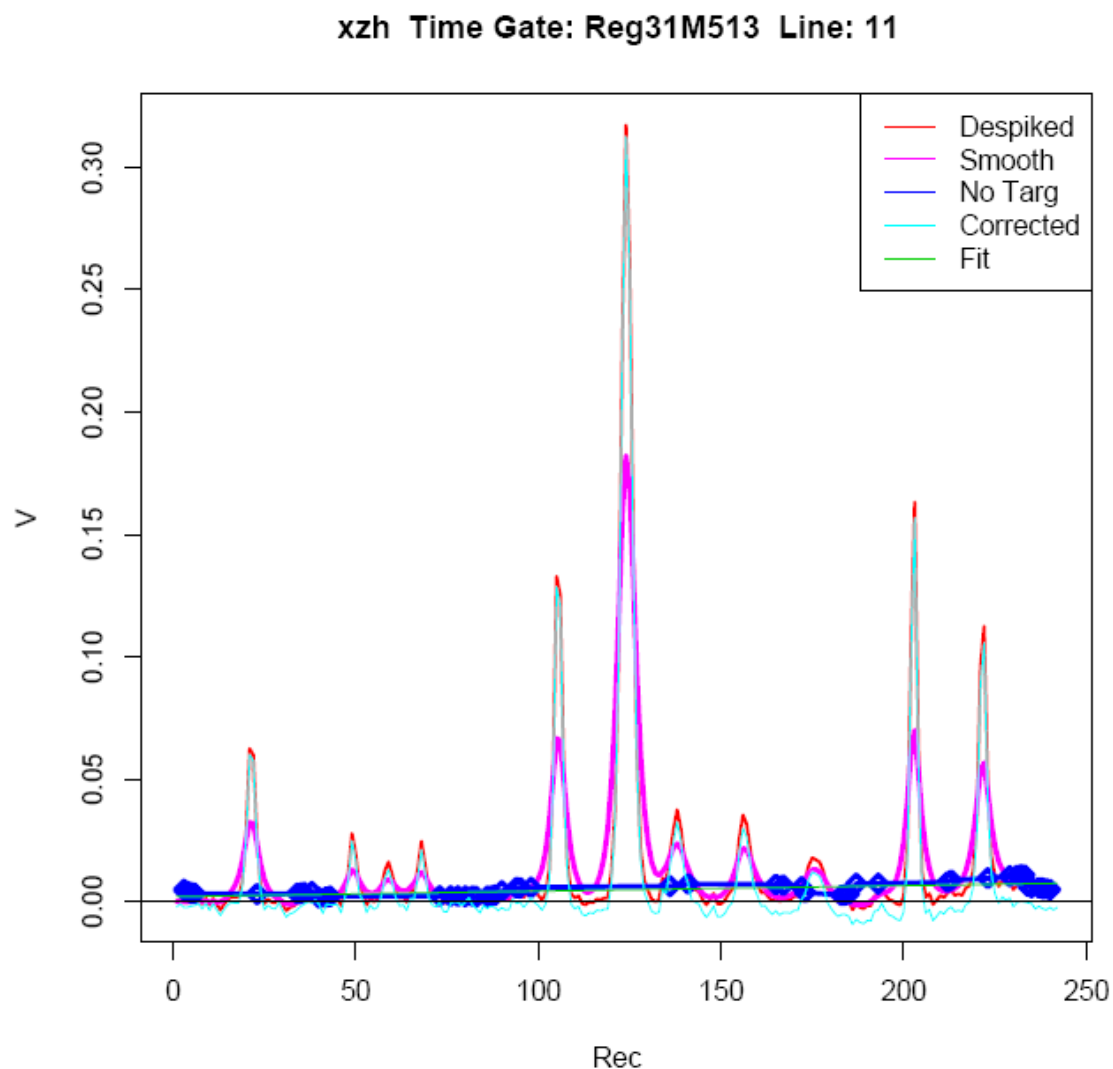
Figure 7.53. An example line with the drift correction algorithm applied. The channel appears to be drifting along line. The dark blue represents target free areas picked by this algorithm and the light blue line represents the drift corrected data. The algorithm works well for lines that are not entirely filled with targets like this one.

This gx is not directly callable from the ALLTEM menu as the algorithm does not perform well on every line. But may be run via the Run Gx module from within Oasis montaj. The algorithm is not robust against lines that contain all targets or lines with no targets that are extremely hashy. This drift problem is serious in older ALLTEM data however and an approach like this may be useful in the future. There are hopes that future ALLTEM data will not contain drift that is not consistent across time gates. Ideally, this algorithm can be abandoned.

7.3.12 usgs_alltem_flip

This GX simply multiplies the grids by -1, effectively flipping negative peaks to positive ones. The target picking algorithm will only pick positive peaks. The channels that are affected are ZX1, ZY1, XZF, XZG, YZG, and YZH.

7.3.13 usgs_alltem_int

This gx convolves a Gaussian kernel across the grid, which gathers up dispersed energy into more of a peak. The effects of this can be seen below.
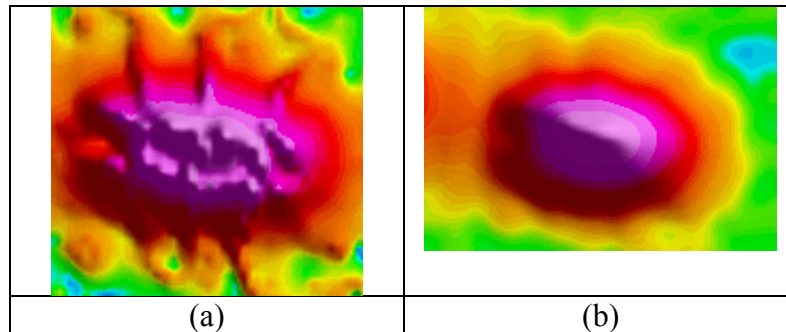
Figure 7.54. Data before (a) and after (b) Gaussian kernel operation for a known single target.

This gx is only run on the analytic signal channels. These channels continue to have multiple peaks associated with each target and the target picking algorithm will pick multiple targets over a single area of anomalous signal. The risk of coarse is that small targets that are close together will be merged. However, since this gx is only acting on the channels that the analytic signal has been computed for, other channels should not have these targets merged.

7.3.14 usgs_alltem_loadstats

After a target free patch has been selected, this gx is called automatically. Its behavior is slightly different depending on whether it is called automatically or manually.

If it is called automatically, the python script ALLTEMDIR\statTemplateMaker.py is called which writes an alltemstats.i3 template file based on the a xxxstats.csv file located in the current directory which allows Oasis motaj to import these files into GDB's. The xxxstats.csv files are generated from the usgs_alltem_targetfree gx.

If this gx is called manually, the user may pick the desired location of a single statsxxx.csv file using the GUI shown below.
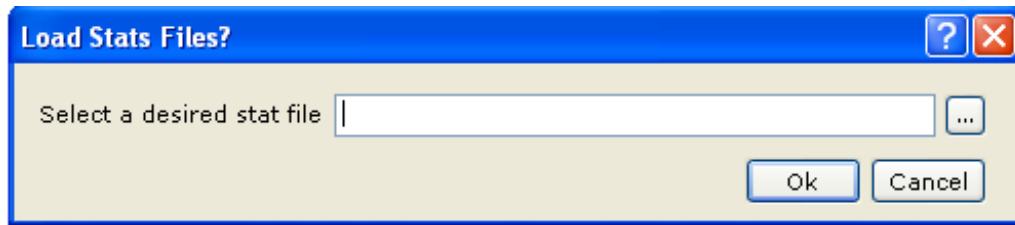
Figure 7.55. Manually select stats files to load, pick only one polarization all will be loaded.

An alltemstats.i3 template will then be generated based on this file and stats files in this folder will be imported. If this folder does not contain a stats file for a particular channel, the program will terminate in error. It is of course necessary to have a stats file for each channel you are wanting to process in the folder you have selected.

7.3.15 usgs_alltem_maskdata

This gx applies the T-test for significance defined in **usgs_alltem_targetfree** to the gridded data channel. All data that are deemed insignificant are given the mean value of the noise. The gx can help reduce false positive picks in clean areas, as the insignificant data will resultantly be very smooth.

7.3.16 usgs_alltem_patchanalysis

This gx may be somewhat misnamed considering the big picture scheme of ALLTEM data flow. This gx determines several parameters about each patch of significant data. The APARS executable program uses some of this information, as well as the classifier. This gx calls an R script *ALLTEMDIR\PatchStats.R*. By default this program will generate a large number of plots, saved as To turn this off

7.3.17 usgs_alltem_patches

This gx draws significant patches around targets based on the significance of each datapoint. For each channel each datum and its two closest neighbors (along that line) are tested for significance. Only the gridded channel is tested and the same test defined in **usgs_alltem_targetfree** is used.   If and only if all three data are significant the central point is considered to be part of a patch. If significant that datum is assigned to the nearest target. After all data for each polarization is tested, and all significant points are assigned to the nearest target, the convex hull of the positions of the significant datapoints is calculated. The convex hull is the smallest bounding ring around which all the points will fit as shown below.
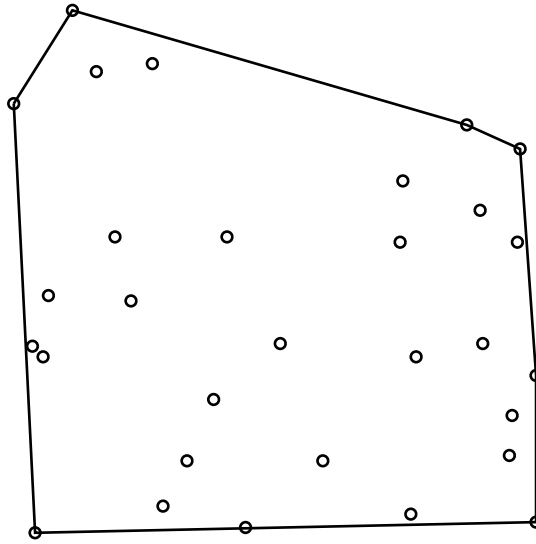
Figure 7.56. The convex hull is a rubber band fit around a cluster of points that contains all the points.

As such the number of points defining a patch is a function of data (line) spacing. The size and shape of the patches are entirely data driven. As usual the α-level of the T-test will affect the threshold at which a datum is deemed to be significant or not.

7.3.18 usgs_alltem_rangrid

This gx simply batch grids an ALLTEM survey. A user is prompted as to which channel to grid and then a minimum curvature grid is created for each channel that is being processed. This method of gridding was selected as it had good performance and reliable results.

7.3.19 usgs_alltem_redrawpatch

This gx allows a user to redraw a patch that was created by **usgs_alltem_patches**. The redrawn patch will be colored in blue, rather than black to distinguish it as being manually overridden.

7.3.20 usgs_alltem_targetfree
7.3.21 usgs_alltem_targetpick
7.3.22 usgs_alltem_wingrid

This gx applies the T-test outlined in usgs_alltem_targetfree to the current grids. Data that does not fall in the significant range is masked.

7.3.23 usgs_alltem

Ths is just a filler gx that is used as a placeholder for future gx's and offers no functionality.

7.3.24 chsubsetoverwrite

A sub-gx that is called from within several other gx's that allows for a database to be subset based on a mask-line. The resulting database overwrites the current database. This is advantageous at times as ALLTEM data contains 19 files for everything, and making numerous subsets of a database creates complex and unwieldy workspaces within Oasis montaj.

7.4   Source Files and Compilation

All source files used in this processing package are available in the *src* directory of the release. The GX's were built using the *gxc*, and *grc* compilers included with GX Developer. Jeff Philips wrote a comprehensive paper about compiling your own gx's in open file report number 2007-1355: **Geosoft eXecutables (GX's) Developed by the U.S. Geological Survey, Version 2.0, with Notes on Gx Development from Fortran Code**.

APPENDIX 1 – ALLTEM Double-Inversion Program Manual

ALLTEM-Double-Inversion
User's Manual

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March 19, 2010

Table of Contents

Overview

As the name implies, ALLTEM-Double-Inversion inverts ALLTEM data to estimate UXO model parameters. The program also has a number of other features, including modeling and calibration. The name ALLTEM-Double-Inversion refers to the fact that both magneto-static and electro-dynamic forward models are used in the inversion. Results from running the program and detailed processing information are placed in the file RunLog.txt in the same directory as executable. The coordinate convention used oriented such that the *y*-axis points in the direction of cart movement during the survey, the *x*-axis points to the right of the cart, and the *z*-axis points up. This is referred to as the ALLTEM convention.

The operation of the program in controlled by three *.ini files which are section files that can be edited with any standard text editor. These *.ini file reside in the same directory as the executable. ALLTEM-Double-Inversion.ini contains keys that identify the data for the program to work with, and which operations to conduct. ALLTEM.ini defines the coil configurations and the calibration values for the response of each coil combination. Finally, ALLTEM-Calibration.ini defines a calibration setup (i.e. locations for the calibration targets), and which target location should be used to calibrate each coil combinations. The details of each section and key used in these files can be found in the Appendix. The basic operation of the program is set by setting one (and only one) of the `Tasks` keys to be `true` in ALLTEM-Double-Inversion. Specific details on these operations (forward modeling, performing calibrations, inverting data, and comparing modeled data with true data) are described in the following sections.

```
[Tasks]
ForwardModel=false
PerformCalibration=false
Inversion=true
CompareModeledDataWithTrueData=false
```

Reading Input Data

ALLTEM-Double-Inversion read two input file data formats, the SU (Seismic Unix) format and the CSV (comma separated values) format. In both file formats, the file naming convention is [name prefix].[Coil Combo mnemonic].[format i.e. 'SU' or 'CSV']. Examples are Yuma.ZZ1.SU and Yuma.ZZ1.CSV. There are 19 standard coil combinations used by the ALLTEM which are defined in ALLTEM.ini. Tables A1 and A2 (see Appendix) lists the mnemonics for each coil combinations as illustrated in Figure A1. The data files are read based on the key values set in ALLTEM-Double-Inversion.ini. The relevant keys are listed below. For each `FilePrefixn` of `NumFilePrefixes`, a data file is read for each coil combination listed in ALLTEM.ini from the directory specified by `Path`. If desired, the magneto-static component of the ALLTEM response can be subtracted from the waveforms if `RemoveStaticComponent` is `true`. For SU files, the waveform value at time-gate 5.50 ms is subtracted from the rest of the waveform. For CSV files, the waveform value in column `StaticSampleIndex` is subtracted from the rest of the waveform. If `ReadCSV` is `true`, then files with the CSV extension are read; if it is `false`, then files with the SU extension are read. The following two paragraphs describe importing data from SU and CSV files respectively.

```
[DataFiles]
ReadCSV=false
StaticSampleIndex=36
RemoveStaticComponent=true
Path=C:\ALLTEM\CompoundTarget\
NumFilePrefixes=6
FilePrefix1=2007-08-23_Clutter_BallBrassTd103_STDd_Ln11
FilePrefix2=2007-08-23_Clutter_BallBrassTd103_STDd_Ln13
FilePrefix3=2007-08-23_Clutter_BallBrassTd103_STDd_Ln15
```

```
FilePrefix4=2007-08-23_Clutter_BallBrassTd103_STDd_Ln17
FilePrefix5=2007-08-23_Clutter_BallBrassTd103_STDd_Ln19
FilePrefix6=2007-08-23_Clutter_BallBrassTd103_STDd_Ln21
```

The SU (Seismic Unix) file format contains the complete waveforms that were recorded during the survey. Each file contains a series of binary records, and each record has a header and a data block. The header is a group of pre-formatted metadata values that describe the data block, and each data block contains a single waveform. The number of samples, instrument location, and other waveform attributes are specified in the header. The SU data file format is simply the SEG-Y format (Barry et al., 1975) with the file header stripped off. Consult the documentation for the Seismic Unix package (Cohen and Stockwell, 2003) for more information. The relevant keys for reading SU files are listed below. The `NumTimeSamples` key sets the number of `TimeSampleIndex'` to read, which are the temporal sample numbers (or time-gates) to read from the recorded waveform. For each waveform read, the noise variance is estimated by calculating the standard deviation of the data from a line drawn between time samples t = 4.5 and 5.5 ms on each waveform.

```
[DataFiles]
NumTimeSamples=5
TimeSampleIndex1=100
TimeSampleIndex2=200
TimeSampleIndex3=300
TimeSampleIndex4=400
TimeSampleIndex5=500
```

Since SU files contain all of the data from a survey, they can be bulky. To reduce bulk, CSV files are used that contain only the desired information to be processed. Each line in a CSV file is a text string that contains numeric values separated by commas. The numerical values in an individual column are all the same type of information (e.g. the x location of the cart, or the waveform amplitude at 1 temporal sample number 31). The first line contains the data labels for each column. Figure 1 shows a typical CSV file.

Line	Rec	Northing	Easting	CubePitch	CubeRoll	CubeYaw	NonFerrP	0	std0	7	std7	22	std22	31	std31	45	std45
28	258	3638382	757702.1	0	0	280.5	0.25	0.006819	0.003517	0.002002	0.000738	0.001163	0.001322	0.000676	0.001636	0.000349	0.001745
28	261	3638382	757701.9	0	0	280.5	0.25	0.005951	0.003517	0.00376	0.000738	0.003004	0.001322	0.002078	0.001636	0.001003	0.001745
28	264	3638382	757701.7	0	0	280.5	0.25	0.009978	0.003517	0.007093	0.000738	0.005253	0.001322	0.004308	0.001636	0.002566	0.001745
28	267	3638382	757701.6	0	0	280.5	0.25	0.010647	0.003517	0.00949	0.000738	0.006615	0.001322	0.00489	0.001636	0.002702	0.001745
28	270	3638382	757701.4	0	0	280.5	0.25	0.018379	0.003517	0.011412	0.000738	0.006801	0.001322	0.004416	0.001636	0.002227	0.001745
28	273	3638382	757701.2	0	0	280.5	0.25	0.013564	0.003517	0.00986	0.000738	0.006278	0.001322	0.004728	0.001636	0.002932	0.001745
28	276	3638382	757701.1	0	0	280.5	0.25	0.011861	0.003517	0.007968	0.000738	0.002675	0.001322	0.0009	0.001636	-0.001189	0.001745
28	279	3638382	757700.9	0	0	280.5	0.25	0.006279	0.003517	0.004847	0.000738	0.000236	0.001322	-0.001245	0.001636	-0.002422	0.001745
30	252	3638382	757702.3	0	0	280.5	0.25	0.005865	0.003517	0.001758	0.000738	0.000516	0.001322	0.000596	0.001636	0.000373	0.001745
30	255	3638383	757702.1	0	0	280.5	0.25	-0.00155	0.003517	0.004669	0.000738	0.004858	0.001322	0.003951	0.001636	0.0026	0.001745
30	258	3638383	757701.9	0	0	280.5	0.25	0.017473	0.003517	0.013879	0.000738	0.011504	0.001322	0.009051	0.001636	0.006385	0.001745
30	261	3638383	757701.7	0	0	280.5	0.25	0.014844	0.003517	0.021414	0.000738	0.018749	0.001322	0.015332	0.001636	0.01121	0.001745
30	264	3638383	757701.6	0	0	280.5	0.25	0.026881	0.003517	0.026949	0.000738	0.022902	0.001322	0.018828	0.001636	0.014413	0.001745
30	267	3638383	757701.4	0	0	280.5	0.25	0.024342	0.003517	0.026385	0.000738	0.0224	0.001322	0.018392	0.001636	0.013895	0.001745
30	270	3638383	757701.2	0	0	280.5	0.25	0.017596	0.003517	0.02105	0.000738	0.016389	0.001322	0.012983	0.001636	0.009047	0.001745
30	273	3638383	757701	0	0	280.5	0.25	0.018748	0.003517	0.013695	0.000738	0.007731	0.001322	0.005155	0.001636	0.002691	0.001745
30	276	3638383	757700.9	0	0	280.5	0.25	0.002801	0.003517	0.00539	0.000738	0.001379	0.001322	-0.000205	0.001636	-0.001232	0.001745
32	231	3638383	757702.2	0	0	280.5	0.25	0.000435	0.003517	0.001823	0.000738	0.003199	0.001322	0.002698	0.001636	0.002512	0.001745
32	234	3638383	757702	0	0	280.5	0.25	0.0051	0.003517	0.004928	0.000738	0.00643	0.001322	0.00549	0.001636	0.004108	0.001745
32	237	3638383	757701.8	0	0	280.5	0.25	0.013246	0.003517	0.008878	0.000738	0.008278	0.001322	0.006633	0.001636	0.005213	0.001745
32	240	3638383	757701.6	0	0	280.5	0.25	0.009507	0.003517	0.009297	0.000738	0.009343	0.001322	0.007786	0.001636	0.006532	0.001745
32	243	3638383	757701.4	0	0	280.5	0.25	0.007091	0.003517	0.008521	0.000738	0.00752	0.001322	0.006407	0.001636	0.004958	0.001745
32	246	3638383	757701.2	0	0	280.5	0.25	0.008962	0.003517	0.006236	0.000738	0.004183	0.001322	0.002979	0.001636	0.001517	0.001745

Figure 1. Example of the contents of a CSV file. Columns are numbered beginning at zero.

ALLTEM-Double-Inversion.ini has keys that instruct the program to read the CSV file (see below). Most of these keys define a zero-based column number for obtaining a certain type of data (see Appendix for more information). The `NumTimeSamples` key sets the number of `TimeSampleIndex'` to read, which are columns containing data from a certain temporal sample number (time-gate) of the recorded waveform. For each `TimeSampleIndex` read, the following column is also read. This succeeding column is assumed to be the standard deviation of the noise for the preceding temporal sample.

```
[DataFiles]
LocationXColumn=3
LocationYColumn=2
CubeRollColumn=4
CubePitchColumn=5
```

```
CubeYawColumn=6
NonFerrousIndicatorColumn=7
NumTimeSamples=5
TimeSampleIndex1=22
TimeSampleIndex2=26
TimeSampleIndex3=28
TimeSampleIndex4=30
TimeSampleIndex5=34
```

After reading the data, several pre-processing operations can be made. Typically, the cube locations measured during a survey are given in maps coordinates such as UTM. In order to have the modeled magnetic fields oriented properly in ALLTEM-centric coordinates, the input coordinates must be translated and rotated. The minimum x and y map coordinates from the survey are used as the ALLTEM-centric origin. The yaw (azimuth) of the ALLTEM cube at each survey point is then used to rotate the survey point into the ALLTEM-centric coordinate system. When reporting estimated parameter values, the inverse of this rotation and translation operation is performed so that parameters are reported in the map coordinate system. To make roll and pitch corrections for each sample point, a bias is added (subtracted) to the target orientation used to model data at each sample point. These orientation corrections are only made when reading in CSV files.

The final operations made on the input data decimate the number of data points chosen to be (typically) less than ~1000 so that the inversion can be accomplished in a reasonable time frame (about a minute using a PC with a 2 GHz 32-bit processor). First, a subset of coil combinations to use in the analysis is selected. In doing so, it is desirable to select the coil combinations that carry the most (orthogonal) information. To select a subset of coil combinations from the recorded set of 19 coil combinations, selections are made in order of increasing noise variance until a single selection for each of the nine possible polarization combinations (i.e. (Tx_x, Rx_x), (Tx_x, Rx_y), etc.) has been made. If more coil combinations are needed to fill the subset, then additional selections are made in order of increasing noise variance.

Next, one of two methods is used for spatial decimation. The first method is used for SU files. If `FilterYLocation` is `true`, then for each line surveyed in the y-direction, only data from `FilterNumYLocations` survey locations are admitted. These y-axis locations begin at `FilterFirstYLocation`, and each successive location is the first location found that is a distance of `FilterYLocationMinInterval` or more from the previous location. To filter data in the x-axis direction, simply select the appropriate group of data files (each SU data file corresponds to a line of survey data).

```
[DataFiles]
NumSelectedCoilCombinations=14
FilterYLocation=false
FilterNumYLocations=6
FilterFirstYLocation=2.5
FilterYLocationMinInterval=-0.15
```

A second method is used for CSV files. Since the locations in a CSV file are not likely to have been recorded from a single survey line, each coil combination is individually thinned until only `NumDesiredSpatialLocations` locations are left. After determining the number of data points to remove, a set is chosen for removal that uniformly span the list of data as it was read in. The data list has the same order as it was listed in the CSV. When deleting data at a spatial location, all temporal samples (time-gate data) with that spatial location are deleted.

```
[DataFiles]
NumSelectedCoilCombinations=14
FilterCSVLocations=false
NumDesiredSpatialLocations=30
```

Simulations

Simulations can be made to generate synthetic data. This is useful for testing 'what if' scenarios. Simulated data are stored in the SU file format. Using the ALLTEM-Double-Inversion keys listed below, the output can be directed to a prescribed directory (`Path`), with file names set by `BaseFileName`. Data files are generated for a number of survey lines as prescribed by `XGridMin`, `XGridMax`, and with the line spacing set by `XGridInt`. For each line, the cube locations are set by `YGridMin`, `YGridMax`, and with the sample spacing set by `YGridInt`. This results in a series of file names such as MyFile-0.XX1.SU, MyFile-0.ZZ1.SU, …, MyFile-1.XX1.SU, MyFile-1.ZZ1.SU, …, MyFile-*n*.XX1.SU, MyFile-*n*.ZZ1.SU, …, for *n* survey lines. Noise can be added to the data if desired. For example, setting `DataNoise=2.0` adds 2 mV RMS random white noise to the simulated waveforms. Setting `UXOOrientationNoise=5.0` results in a random orientation noise to the target with a standard deviation of 5.0 degrees to be used when simulating data. This has the effect of simulating orientational uncertainty due to rough ground. Finally, setting `CartPositionNoise=0.01` results in a random location noise with a standard deviation of 1.0 cm to be used when simulating data. This is useful for simulating uncertainty in GPS positions.

```
[ForwardModelSettings]
Path=C:\ALLTEM\CompoundTarget\
BaseFileName=ALLTEM-Simulation
DataNoise=0.0
UXOOrientationNoise=0.0
CartPositionNoise=0.0
XGridMin=2.2
XGridMax=3.2
XGridInt=0.2
YGridMin=1.4
YGridMax=2.6
YGridInt=0.2
```

The UXO section defines the UXO parameters that are used when simulating data. The electrical properties, position, orientation, and spheroid pricipal radii are specified as shown below and described in the Appendix.

```
[UXO]
Sigma=4.566e6
Mu=55.0
Xpos=2.1
Ypos=2.6
Zpos=-0.38358
Azimuth=0.0
Inclination=0.0
Raxial=0.0502
Rtransverse=0.0500
```

Calibration

Calibration is a very important requirement to be able to properly invert field data to estimate UXO characteristics. Calibration is performed by placing a spherical target with known properties at a known location, and recording the ALLTEM response. Then ALLTEM-Double-Inversion is used to determine the linear calibration coefficients. Setup the `[DataFiles]` section to read in the recorded ALLTEM response, and the `[UXO]` section to reflect the properties of the calibration target. The location of the target is specified ALLTEM-centric coordinates – that is, the *x* and *y*-axis origin is the center of the cube, and the *z*-axis origin is below the cube at the ground

surface. The cube height above the ground is specified in the ALLTEM.ini file key `CubeCenterHeight`.
NOTE: *the spheroid model must be either oblate or prolate, which means that the spheroid axial and transverse*
principal radii should not be precisely equal. Adding 0.2 mm to one of the principal radii will not cause adverse
effects. If `WriteCalibrationValues` is `true`, then the calibration coefficients are determined and written to
the ALLTEM.ini file.

```
[Calibration]
WriteCalibrationValues=true
UseAlltemCalibrationIni=true

[UXO]
Sigma=4.566e6
Mu=55.0
Xpos=2.1
Ypos=2.6
Zpos=-0.38358
Azimuth=0.0
Inclination=0.0
Raxial=0.0502
Rtransverse=0.0500
```

Because some coil combinations may have a small response to a target in a single location, calibrations are
normally conducted by placing a spherical target at three different locations. These target locations are referred to as
the X, Y, and Z locations, which describe target positions with the largest offsets from the center of the cube in the
x, *y*, and *z*-axis directions respectively. If `UseAlltemCalibrationIni` is `true`, then the three target locations
are taken from the ALLTEM-Calibration.ini file. ALLTEM-Calibration.ini also defines which target positions are
used to calibrate each coil combination (`File_extension` and `UseTargetPosition` keys).

```
[ALLTEM_System_Definition]
NumCoilCombos=19
TargetPositionX_x=-0.7743
TargetPositionX_y=0.0
TargetPositionX_z=0.3839
TargetPositionY_x=0.0
TargetPositionY_y=-0.7743
TargetPositionY_z=0.3839
TargetPositionZ_x=0.0
TargetPositionZ_y=0.0
TargetPositionZ_z=1.6606

[Combination_1]
File_extension=zzm
UseTargetPosition=z
```

When using locations from the ALLTEM-Calibration.ini file, the data file names specified in ALLTEM-Double-
Inversion.ini for the measured response must end in an X, Y, or Z to identify the target location used when recording
the file.

```
[DataFiles]
NumFilePrefixes=3
FilePrefix1=2007-07-16_CalPmSsX_FltMinBak_Ln0-FixedX
FilePrefix2=2007-07-16_CalPmSsY_FltMinBak_Ln0-FixedY
FilePrefix3=2007-07-16_CalPmSsZ_FltMinBak_Ln0-FixedZ
```

Inversion

The main function of the program is to estimate UXO parameters from ALLTEM data. These parameters include the electrical properties of the target, its location, and the principal radii of a spheroid that is used to model the target response. According to O'Neill (2002), the mid-frequency (~50 Hz to ~20 kHz) response of compact targets can be reasonably approximated by dipoles – even if they are irregularly shaped. This is because mid-frequency induced currents circulate within the object's volume. The spheroid (ellipsoid) model used in ALLTEM-Double-Inversion models the response along each of the principal spheroid axes as an induced dipole. Details of the modeling can be found in Oden (2010). The inversion minimizes the (weighted) least squares error between the modeled data and the measured data. The objective function (i.e. least squares error) is minimized from its starting value using the Gauss-Newton method. Several values are reported while the inversion is executing. The *Step Size* is the distance moved during each iteration in parameter space. *ParamsErr* is the product of the inverse Jacobian and the data error; it gives an indication of the steepness of the local topography of the objective function. Finally, the *mean squared error (MSE)* is the data error energy normalized by the energy in the data.

The inversion progresses through a number of stages starting with an initial prolate model of the target. Each stage is optionally executed as follows. If `Stage1ProlateSpheroid` is `true`, then optimal parameters for a prolate spheroidal target are found starting with the initial model. Next, if `Stage2OblateSpheroid` is `true`, then optimal parameters for an oblate spheroidal target are found starting with the initial prolate model, but switching the major and minor axis lengths. Then, if `Stage3Ellipsoid` is `true`, then optimal parameters for an ellipsoidal target are found starting with the most optimal parameters found from the previous two stages. In stages 1-3, the material properties are held fixed at their initial values (described below). Finally, if `Stage4PolishMaterialProps` is `true`, then the target location and spheroid (ellipsoid) diameters are held fixed and an optimal conductivity value is sought. The reason several stages are executed is because 1) without holding prolate/oblate constant while searching for a global solution, problems may arise early in the solution search, and 2) there is a basin of attraction for prolate solutions, and another for oblate solutions. Early searches with large errors may get caught in the wrong basin of attraction, therefore a solution from both basins is sought. This sequence can be repeat several times with several different initial prolate models.

```
1. Select initial prolate model
2. Find optimal prolate parameters from initial prolate model
3. Find optimal oblate parameters from initial oblate model
4. Find optimal ellipsoid parameters from model so far
5. Find optimal material properties
6. Select another initial prolate model and repeat sequence
```

```
[Inversion]
NumIterations=30
Stage1ProlateSpheroid=true
Stage2OblateSpheroid=false
Stage3Ellipsoid=false
Stage4PolishMaterialProps=false
OLSnotWLS=true
NumInitialModels=1
AutoInitialLocation=true
AutoMaterialProps=false
GeneticModelSelection=false
RandomModelSelection=false
NewModelThresholdMSE=0.05

[UXO_1]
;Inital models must be prolate.  Major and minor axes are
switched for oblate initial models.
Mu=100.0
Sigma=8.5e6
```

```
Xpos=2.078
Ypos=-0.810
Zpos=-0.55
Azimuth=0.0
Inclination=0.0
Raxial=0.052
Rtransverse=0.05
```

Figure 1 shows the flow chart for finding a global solution. First a prolate solution is sought. The search is terminated when a local minimum is encountered or the maximum allowable number of iterations has elapsed. Next an oblate solution is sought. When searching for prolate and oblate solutions μ_r and σ are held fixed at nominal values to limit the degrees of freedom. The nominal conductivity values is $1.0 \cdot 10^7$ S/m (aluminum alloys typically range from $1.5 \cdot 10^7$ to $3.5 \cdot 10^7$ S/m, and steel typically alloys range from $0.2 \cdot 10^7$ to $0.86 \cdot 10^7$ S/m). The nominal relative permeability is 100 for ferrous objects and 1 for non-ferrous objects. Relative permeability values for steel typically range from 50 to 500, however, due to the demagnetization effect, there is little difference in the response for permeabilies in this range for objects with aspect ratios less than four. Finally, if PolishMaterialProps is true, then the solution is polished by allowing σ to change, and holding roll, pitch and yaw fixed. Since most of the energy in the ALLTEM response is due to the magneto-static response, this step is usually not necessary unless early time (< 1 ms) data are used.

The ALLTEM coordinate convention is that Z is positive up and that survey lines are run in the positive Y direction with the positive Y face of the cube facing forward. All parameters in the *.ini files use the ALLTEM coordinate convention. Internally, ALLTEM-Double-Inversion uses Z is positive down and that survey lines are run in the positive X direction with the positive X face of the cube facing forward.
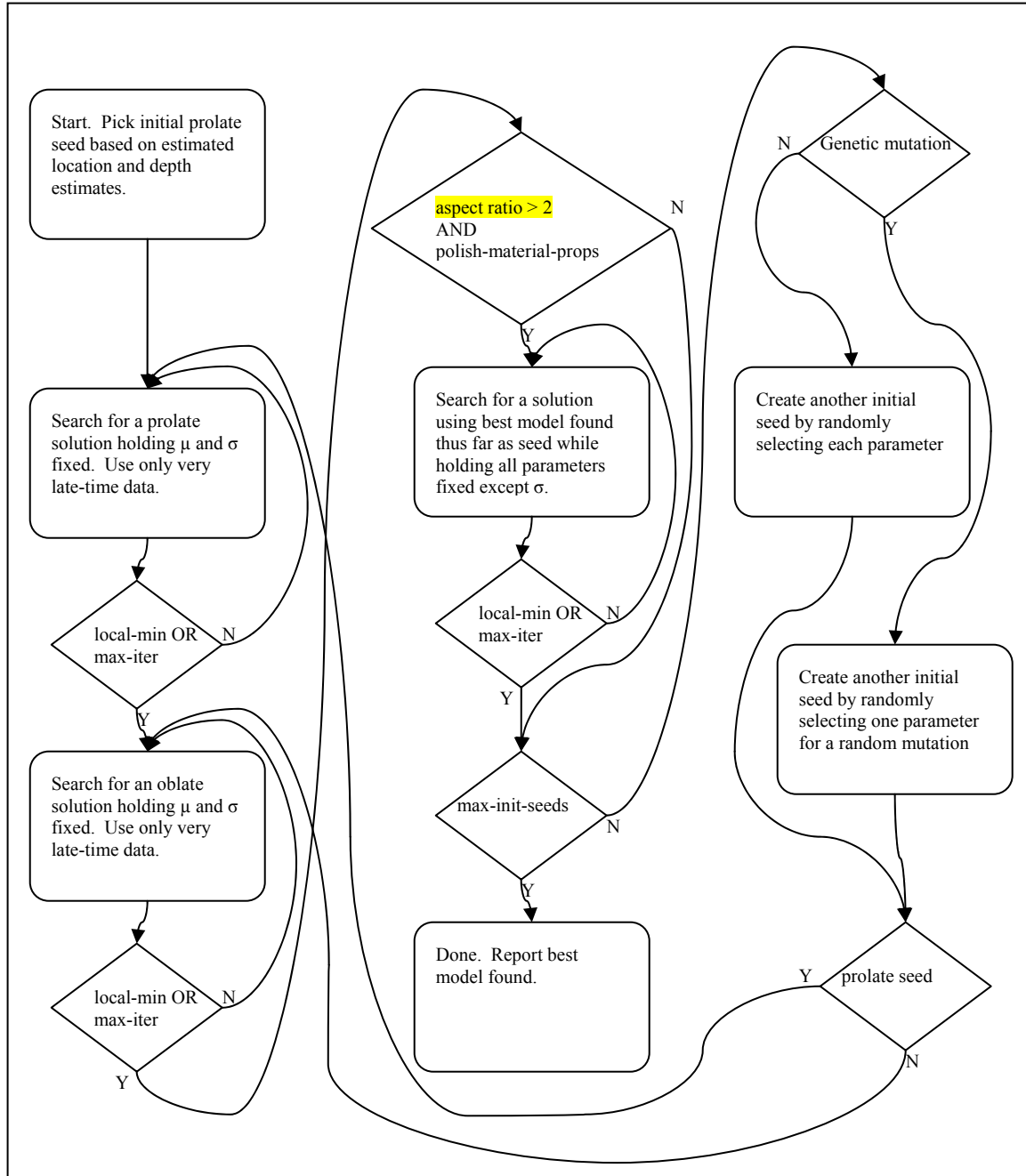
Figure 2. Flow chart for finding a global solution.

Comparing Modeled Data with Measured Data

ALLTEM-Double-Inversion can compare modeled data with actual data. This is useful for verifying that the coil definitions listed in ALLTEM.ini are correct and checking for instrument drift from a base calibration. This task reads in the data files according to the `[DataFiles]` section, and generates waveform data based on the target specified in the `[UXO]` section. Files with the names CalibrationDifference.XX1.SU, CalibrationDifference.ZZ1.SU, …, CalibrationData.XX1.SU, CalibrationData.ZZ1.SU, …, and CalibrationModel.XX1.SU, CalibrationModel.ZZ1.SU, …, will be generated. Each SU file will contain records

corresponding to the data that were read in and survived decimation. Plotting these files with a program such as GP Workbench (Oden and Moulton, 2007) can be very insightful.

References

Barry, K.M., Cavers, D.A., and Kneale, C.W., 1975, Report on Recommended Standards for Digital Tape Formats, Geophysics, n. 40, v. 2, pp. 344-352.

Cohen, J.K., and Stockwell, J.W., Jr., 2003, CWP/SU: Seismic Unix release 37: a Free Package for Seismic Research and Processing: Center for Wave Phenomena, Colorado School of Mines, Golden, Colorado, 141 p.

Oden, C.P., 2010, Combining Advances in EM Induction Instrumentation and Inversion Schemes for UXO Characterization, IEEE Trans. Geoscience and Remote Sensing, submitted.

Oden, C.P., and Moulton, C.W., 2007, GP Workbench Manual: Technical Manual, User's Guide, and Software Guide, U. S. Geological Survey Open-File Report 2006-1365, 81 p.

O'Neill, K., 2002, Ultra-Wideband Electromagnetic Induction for UXO Discrimination, SERDP Project CU-122, Final Report, 177 p.

Appendix

Source Code Notes

As mentioned previously, the coordinate convention used oriented such that the y-axis points in the direction of cart movement during the survey, the x-axis points to the right of the cart, and the z-axis points up. Internally, ALLTEM-Double-Inversion used the NED (north, east, down) convention for its x, y, and z- axis directions. This choice was made to be consistent with pre-existing modeling code that was used as a basis for the forward model used in ALLTEM-Double-Inversion. When spatial parameters are read from an *.ini file or an input data file, the coordinates are converted to the NED convention. Conversely, spatial parameters are converted to the ALLTEM convention before they are reported to the user.

The ALLTEM-Double-Inversion executable included in the initial release was compiled using Microsoft Visual Studio 2005. Some computers may need to install the necessary C runtime libraries. These can be download

ALLTEM-Double-Inversion.ini

The tasks performed ALLTEM-Double-Inversion.exe are controlled by the file ALLTEM-Double-Inversion.ini. This file contains keys whose definition directs the program. The keys are described in the table below.

Section	Key	Example Value	Description
[Tasks]	ForwardModel	true	
	PerformCalibration		
	Inversion		
	CompareModeledDataWithTrueData		
[ForwardModelSettings]	Path		Name of directory to place output files. Last character should be a backslash. Relative path

			<mark>names???</mark>
	BaseFileName		File name for output files. This name will have a suffix appended to represent the coil combination (i.e. .zzm.SU)
	DataNoise		Standard deviation of normal distribution (in calibrated volts)
	UXOOrientationNoise		Standard deviation of normal distribution (in degrees)
	CartPositionNoise		Standard deviation of normal distribution (in meters)
	XGridMin		Minimum X coordinate for conducting
	XGridMax		<mark>Need to reverse X and Y when reading values from ini file to account for different coordinate conventions.</mark>
	XGridInt		
	YGridMin		Minimum Y coordinate of each line of data.
	YGridMax		
	YGridInt		
[Calibration]	WriteCalibrationValues		
[UXO]	Sigma	1.0e7	Conductivity value used for modeling and as the initial value for the inversion
	Mu		Relative magnetic permeability value used for modeling and as the initial value for the inversion
	Xpos		X UXO location value used for modeling and as the initial value for the inversion
	Ypos		Y UXO location value used for modeling and as the initial value for the inversion
	Zpos		Z UXO location value used for modeling and as the initial value for the inversion
	Azimuth		UXO azimuth value used for modeling and as the initial value for the inversion
	Inclination		UXO inclinaiton value used for modeling and as

			the initial value for the inversion
	Raxial		Radius of long axis of UXO spheroid used for modeling and as the initial value for the inversion
	Rtransverse		Radius of short axis of UXO spheroid used for modeling and as the initial value for the inversion
[Inversion]	NumIterations		
	NumInitialModels		
	DataVariance		No longer used
	GeneticMutations		
	HoldMinorDiametersEqual		
	PolishMaterialProps		
	UseGivenStartingModel		
[DataFiles]	ReadCSV	true	
	LocationXColumn	2	
	LocationYColumn	3	
	CubeRollColumn	4	
	CubePitchColumn	5	
	CubeYawColumn	6	
	NumTimeSamples		
	TimeSampleIndex1		Sample number if reading and SU file. Column number if reading a CSV file.
	RemoveStaticComponent		If this is true, then the value at sample 550 is subtracted from the data points, and only the electro-dynamic model is used. This is not recommended because there is still transient energy at late times.
	Path		
	NumFilePrefixes		
	FilePrefix1		
	NumSelectedCoilCombinations		
	FilterXLocation	true	SU files only
	FilterNumXLocations		SU files only
	FilterFirstXLocation		SU files only
	FilterXLocationMinInterval		SU files only
	SaveInputData	true	SU files only

Table A1. Listing of ALLTEM-Double-Inversion contents.

ALLTEM.ini

The file ALLTEM.ini contains information on the coil combinations and their corresponding file extensions. This file is used when reading data to obtain a list of file extensions used in the survey. ==Add calibration uncertainty==

Section	Key	Example	Description

|		Value	
[ALLTEM_System_Definition]	NumCoilCombos	true	
	CubeCenterHeight	0.678	
[Combination_1]	File_extension	zzm	
	TX_polarity	0	
	RX-polarity	2	
	RX_midpoint_position_x	0.123	
	RX_midpoint_position_y	0.123	
	RX_midpoint_position_z	0.123	
	RX_offset_x	0.123	
	RX_offset_y	0.123	
	RX_offset_z	0.123	
	TXCoilHalfWidth	0.5	
	RXCoilHalfWidth	0.5	
	CalibrationFactor	0.1234567	
	CalibrationUncertainty	0.0123456	

Table A1.
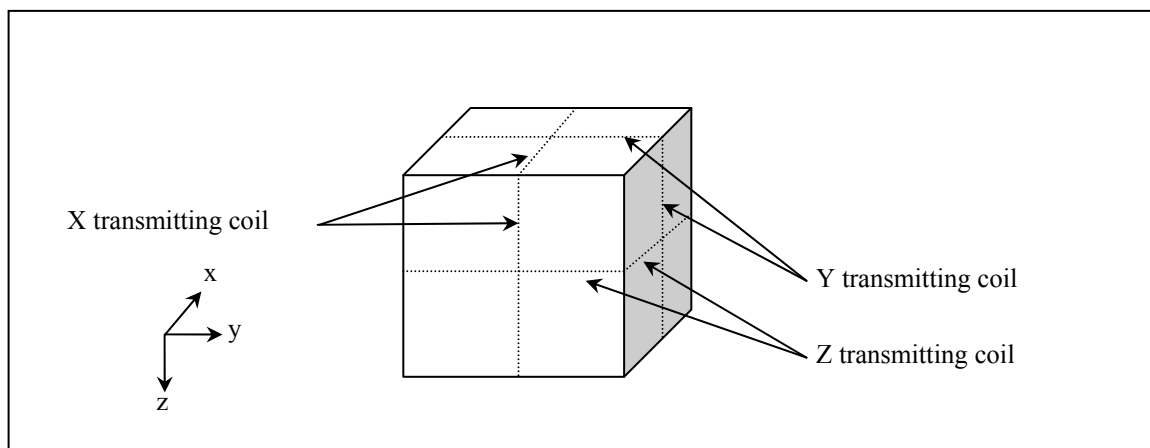
Figure A1. ALLTEM cube showing transmitter coil locations.

Mnemonic	Coil side length	Midpoint (x, y, z)	Offset (x, y, z)
zzm	1.0	(0.0, 0.0, 0.0)	(0.0, 0.0, +/-0.5)
xzm	1.0	(0.0, 0.0, 0.0)	(0.0, 0.0, +/-0.5)
yzm	1.0	(0.0, 0.0, 0.0)	(0.0, 0.0, +/-0.5)
zzh	0.175	(0.0, 0.0, 0.0)	(0.25, -0.25, +/-0.5)
xze	0.175	(0.0, 0.0, 0.0)	(0.25, 0.25, +/-0.5)
yze	0.175	(0.0, 0.0, 0.0)	(0.25, 0.25, +/-0.5)
zze	0.175	(0.0, 0.0, 0.0)	(0.25, 0.25, +/-0.5)
xx1	0.175	(0.0, 0.0, 0.292)	(+/-0.5, 0.0, 0.0)
yy1	0.175	(0.0, 0.0, 0.292)	(0.0, +/-0.5, 0.0)
xzf	0.175	(0.0, 0.0, 0.0)	(-0.25, 0.25, +/-0.5)
yzg	0.175	(0.0, 0.0, 0.0)	(-0.25, -0.25, +/-0.5)
yzf	0.175	(0.0, 0.0, 0.0)	(-0.25, 0.25, +/-0.5)
yzh	0.175	(0.0, 0.0, 0.0)	(0.25, -0.25, +/-0.5)
zzf	0.175	(0.0, 0.0, 0.0)	(-0.25, 0.25, +/-0.5)
zzg	0.175	(0.0, 0.0, 0.0)	(-0.25, -0.25, +/-0.5)
xzg	0.175	(0.0, 0.0, 0.0)	(-0.25, -0.25, +/-0.5)
xzh	0.175	(0.0, 0.0, 0.0)	(0.25, -0.25, +/-0.5)
zx1	0.175	(0.0, 0.0, 0.292)	(+/-0.5, 0.0, 0.0)

zy1	0.175	(0.0, 0.0, 0.292)	(0.0, +/-0.5, 0.0)

Table A2. ALLTEM coil parameters. All dimensions in meters. Coil mnemonics are listed in order of decreasing amplitude for a steel ball target.

ALLTEM-Calibration.ini

The calibration routine reads in all data files listed in the [DataFiles] section. When performing a calibration, all data files listed in the [DataFiles] section of ALLTEM-Double-Inversion.ini for a particular coil combination (e.g. zzm) must be for the location (X, Y, or Z location) of the calibration standard listed in ALLTEM-Calibration.ini. Files used for calibration must have the following naming convention.

*X.ppp.SU	Calibration standard in the X position
*Y.ppp.SU	Calibration standard in the Y position
*Z.ppp.SU	Calibration standard in the Z position

Table A3.

The 'ppp' field is the portion of the file name indicating the coil combination. The file ALLTEM-Calibration.ini contains information for interpreting these files.

Section	Key	Example Value	Description
[ALLTEM_System_Definition]	NumCoilCombos	true	
	TargetPositionX_x	0.123	
	TargetPositionX_y	0.123	
	TargetPositionX_z	0.123	
	TargetPositionY_x	0.123	
	TargetPositionY_y	0.123	
	TargetPositionY_z	0.123	
	TargetPositionZ_x	0.123	
	TargetPositionZ_y	0.123	
	TargetPositionZ_z	0.123	
[Combination_1]	File_extension	zzm	
	UseTargetPosition	x	

Table A4.

Default listing of ALLTEM-Calibration.ini
```
 [ALLTEM_System_Definition]
 NumCoilCombos=10
 TargetPositionX_x=-1.006
 TargetPositionX_y=0.014
 TargetPositionX_z=-0.3696
 TargetPositionY_x=-0.003
 TargetPositionY_y=1.011
 TargetPositionY_z=-0.3836
 TargetPositionZ_x=0.01394
 TargetPositionZ_y=0.00294
 TargetPositionZ_z=0.32842
;
 [Combination_1]
 File_extension=zzm
 UseTargetPosition=z
;
 [Combination_2]
 File_extension=xzm
```

```
 UseTargetPosition=x
;
 [Combination_3]
 File_extension=yzm
 UseTargetPosition=y
;
 [Combination_4]
 File_extension=zzh
 UseTargetPosition=z
;
 [Combination_5]
 File_extension=xze
 UseTargetPosition=z
;
 [Combination_6]
 UseTargetPosition=z
;
 [Combination_7]
 File_extension=zze
 UseTargetPosition=z
;
 [Combination_8]
 File_extension=xx1
 UseTargetPosition=x
;
 [Combination_9]
 File_extension=yy1
 UseTargetPosition=y
;
 [Combination_10]
 File_extension=xzf
 UseTargetPosition=z
;
 [Combination_11]
 File_extension=yzg
 UseTargetPosition=z
;
 [Combination_12]
 File_extension=yzf
 UseTargetPosition=z
;
 [Combination_13]
 File_extension=yzh
 UseTargetPosition=z
;
 [Combination_14]
 File_extension=zzf
 UseTargetPosition=z
;
 [Combination_15]
 File_extension=zzg
 UseTargetPosition=z
;
 [Combination_16]
 File_extension=xzg
 UseTargetPosition=z
;
```

```
[Combination_17]
File_extension=xzh
UseTargetPosition=z
```

APPENDIX 2 – Selected LabView Source Code

This appendix documents the operation of certain software functions and includes descriptions of some of the relevant LabView routines. LabView programmers may find this information especially useful.

Function performed by "FindGPSGaps&NonRTK_c.vi"

In the user input panel that appears when the **Find GPS Problems** button is clicked:
1. Select a survey line file in the directory of the data you wish to find bad GPS
2. Select the lines of the survey to process. (The program will skip any lines that you have previously indicated to skip in the **Site Specific Setting** entry)
3. When all selections have been made, click the **ACCEPT** button

The program will start processing all of the lines indicated, using the ".zzm", ".yy1", and ".xx1" polarities only for the decision making process. They have all of the information in their headers to determine if there are GPS problems. The program performs the following actions:
- For each of the three polarities, extract the GPS information out of the headers of each record on a given line.
- Check if the UTC in the header is blank. This is an indication that the GPS unit was not receiving any GPS information from the GPS on the rover. If found, record the line number and the waveform record number in the array which keeps track of the missing GPS headers for the polarity being processed. These arrays are the ones labeled "MissingHeadGPS X", "MissingHeadGPS Y", and "MissingHeadGPS Z" in the Site Specific Settings configuration file (".sss").
- If there is a non-blank UTC value and the GPSMode value in the header is not "4" (RTK_FX), then record the value of the UTC and the line number into the array which keeps track of the bad (non-RTK_FX) GPS values. These arrays are the ones labeled "BadGPS X", "BadGPS Y", and "BadGPS Z" in the Site Specific Settings configuration file (".sss").
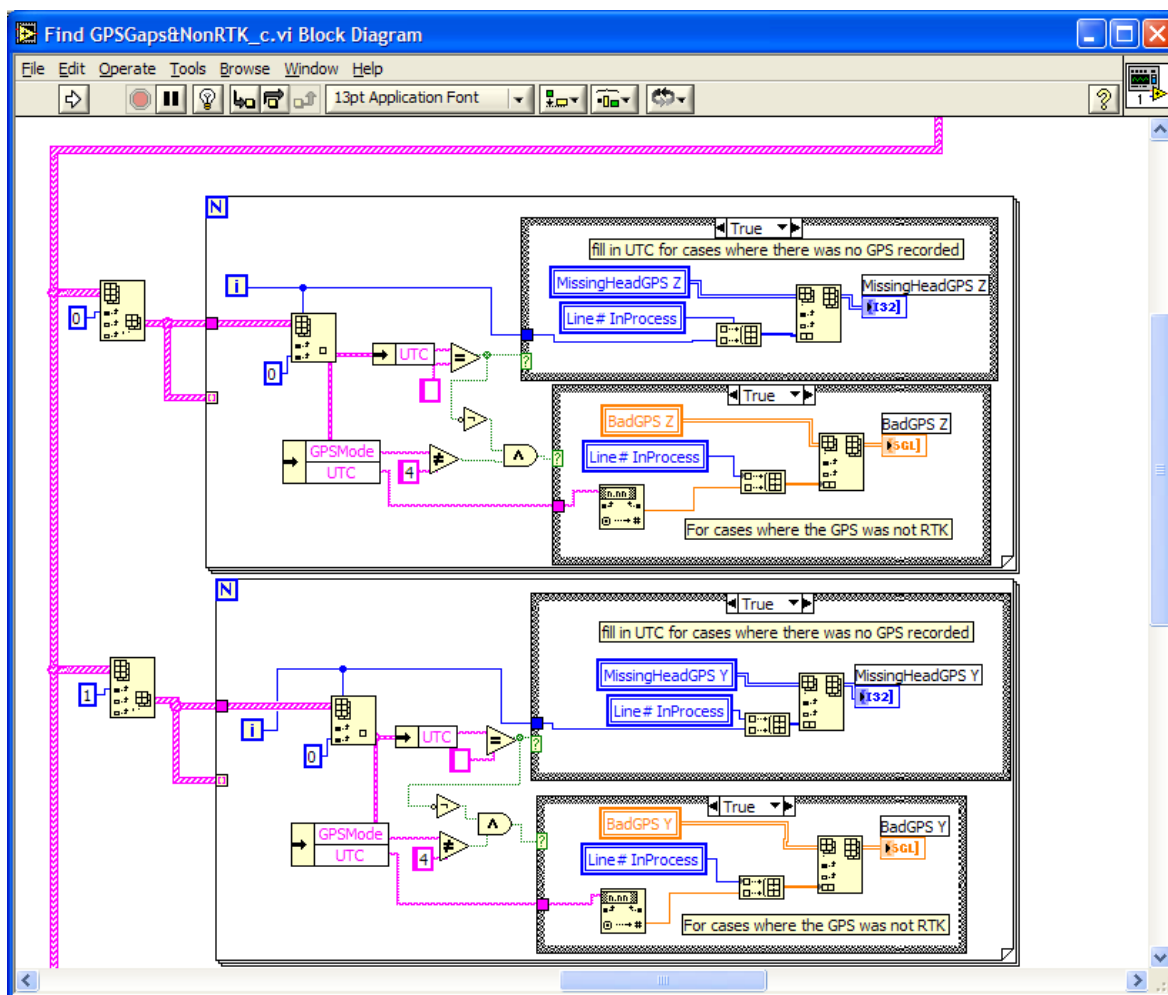
Figure A2.1. Screen shot of a portion of the process of identifying the missing headers and non–RTK_FX values.

Function performed by "FindRollingBgndStartPoint_e.vi"

Note: The algorithm describe here (revision _e) was used for the data processed from the Aberdeen Proving Grounds survey in 2010. It worked well for that data set, where for the majority of each line, there were no targets under the ALLTEM cube. It was discovered that it did not work as well when the survey lines were driven over areas that were predominately covered with metallic objects. In those cases, manually picking the "quiet" areas (areas with no decays in the waveform due to metallic items), was a better way to find the background subtraction start points.

In the user input panel that appears when the **Find Background Subtraction** Start button is clicked:
1. Select a survey line file in the directory of the data you wish to find the rolling background subtraction starting points.
2. Select the lines of the survey to process. (The program will skip any lines that you have previously indicated to skip in the **Site Specific Setting** entry)
3. When all selections have been made, click the **ACCEPT** button.

For each line of each polarity checked:

- For each raw waveform, average picks 31 to 41 and picks 513 to 523. This is done to keep from picking a single noisy 31 or 513 waveform value. Subtract the averaged 513 values from the averaged 31 values (AVG PICK). Place each AVG PICK value into the AVG PICK ARRAY
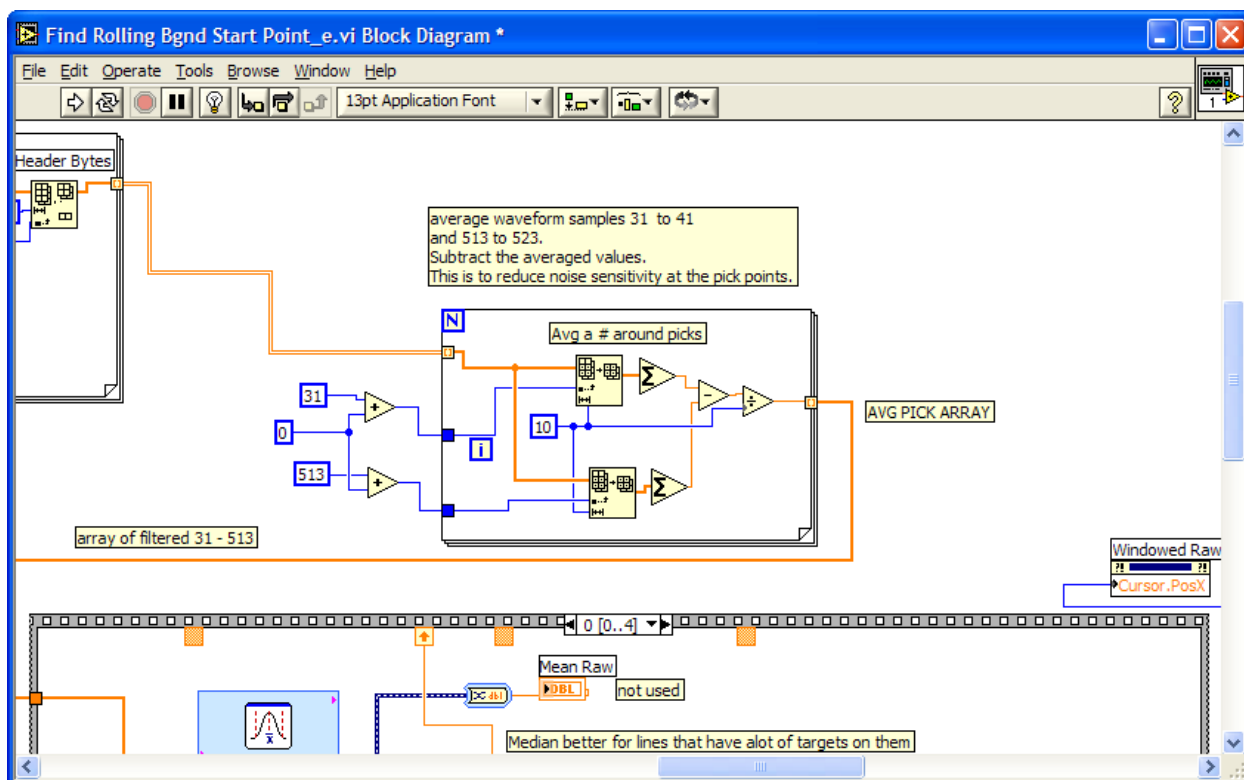
Figure A2.2. Screen shot of process of averaging waveform values around picks 31 and 513 and subtracting.

- Perform statistics on the AVG PICK ARRAY values to get the median value (MED RAW). The median value is a better statistical measure than the mean for lines that have many targets (ordnance or clutter items) on them.
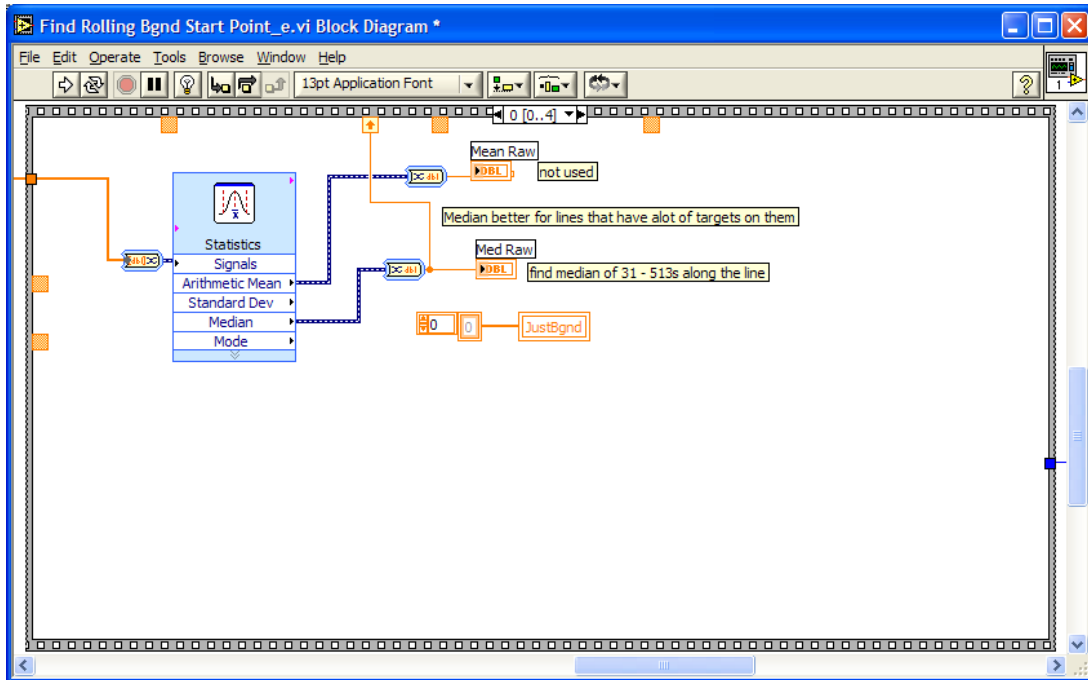

Figure A2.3. Screen shot of process of determining the median of the AVG PICK ARRAY.

- Subtract the MED RAW value from the original AVG PICK ARRAY to create the RAW–MED RAW array. This moves the AVG PICK ARRAY values closer to zero, if the line is largely composed of closely spaced targets which never allow the receiving antennas to see areas with no targets.

- Perform a windowing function on the RAW-MED RAW array to identify array values that outside of a user defined window limit (RAW WINDOW RANGE).   Currently the RAW WINDOW RANGE is hard-coded to +/- 0.005 volt. This is done to remove areas of the line that have large targets so that statistics can be performed on the quieter parts of the line.
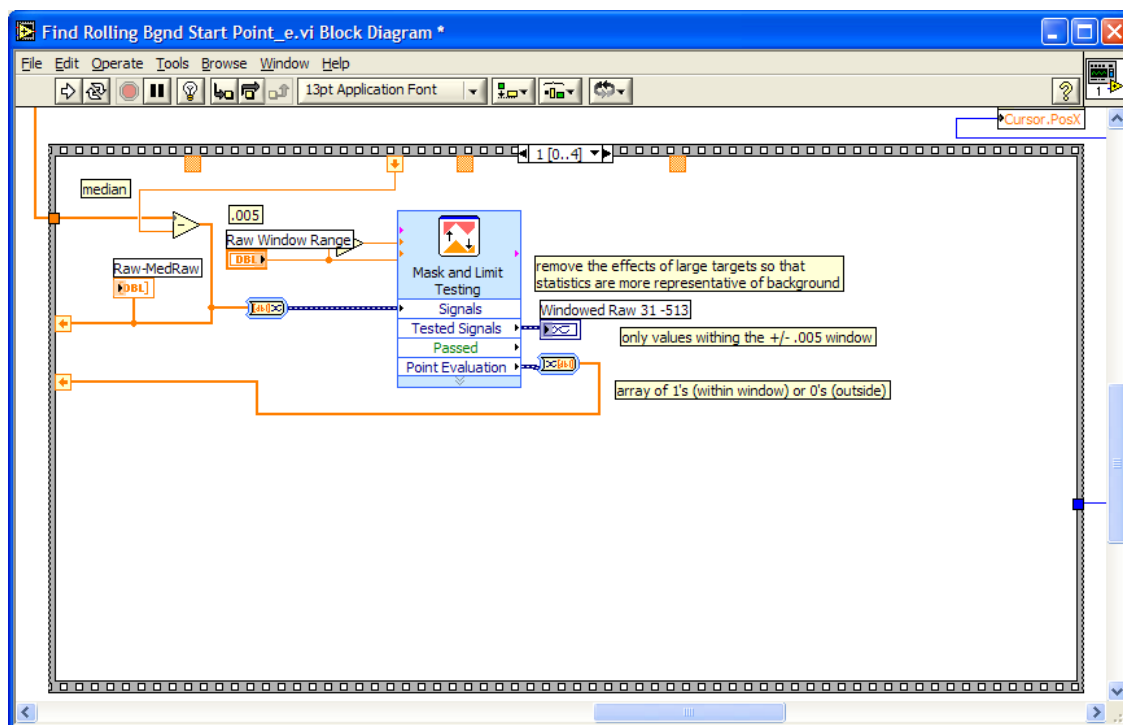
Figure A2.4. Screen shot of subtracting the median value and windowing the array.

- Create an array that has only the quiet parts of the AVG-MED RAW array and perform statistics on it to find the mean value (MEAN JUST BGND).
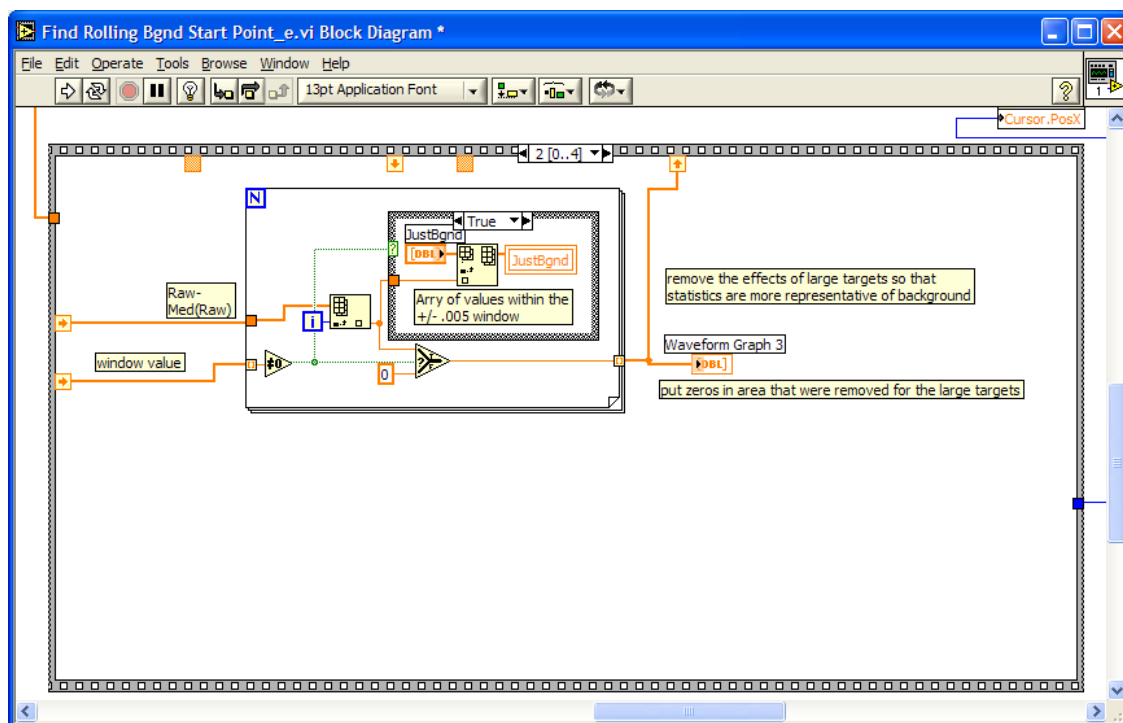

Figure A2.5. Screen shot of the process of removing samples that are outside the window.

- Subtract the MEAN JUST BGND value from the WINDOWED AVG-MED RAW array. This array is called the SHIFTED WINDOWED RAW-MED RAW array. This performs a second centering of the array around zero, without the big targets.
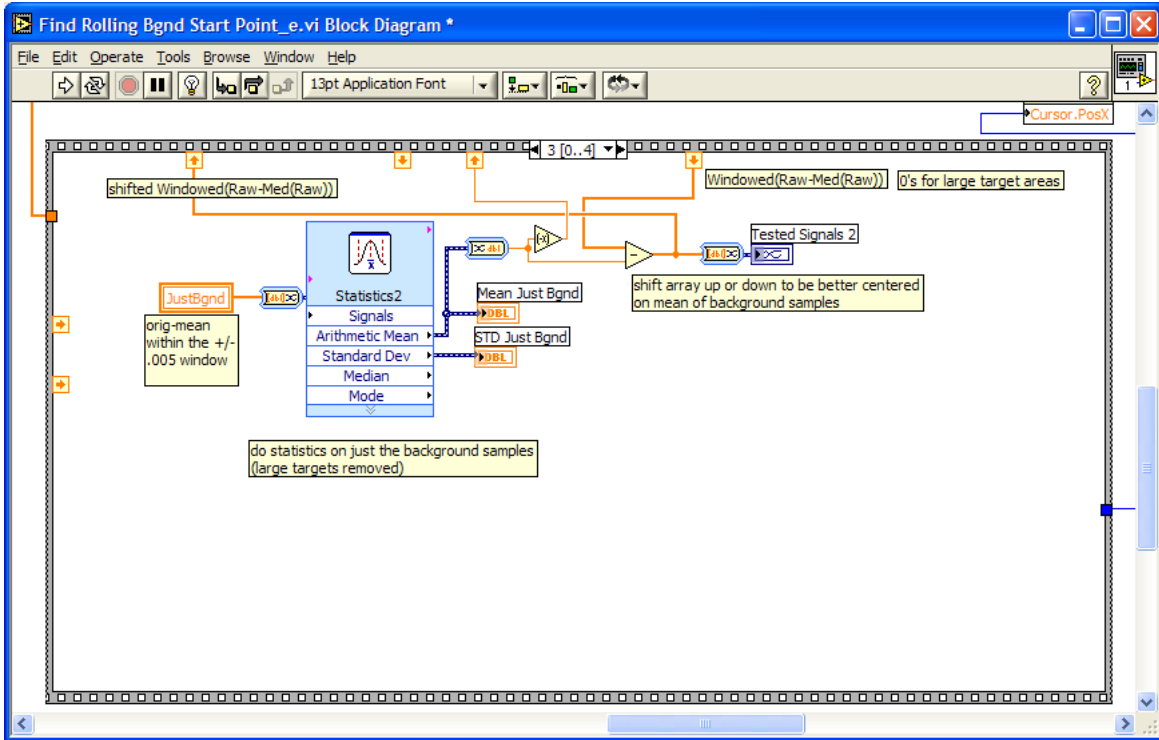

Figure A2.6. Screen shot of the process of performing statistics on quiet areas and level shifting.

- Look at values 0 − 10 in the SHIFTED WINDOWED RAW-MED RAW array and compute the mean and standard deviation. Store those values temporarily. Look at samples 1 − 11 and compute the mean and standard deviation. Compare those values with the previously calculated values. If both the mean and standard deviation values are lower than the previous ones, then store the record number of the start of the current waveform group being processed (for example, 1 in group 1 to 11). Repeat this process up until to the last group of 10 waveforms on the line are processed. This loop will exit with the first record number in the waveform group whose statistics had the lowest combination of mean and standard deviations. This is the value that is stored in the **Rolling Bgnd No Target Start Waveform** field of the **Site Specific Settings** configuration file ("·sss") for that line and that polarity.
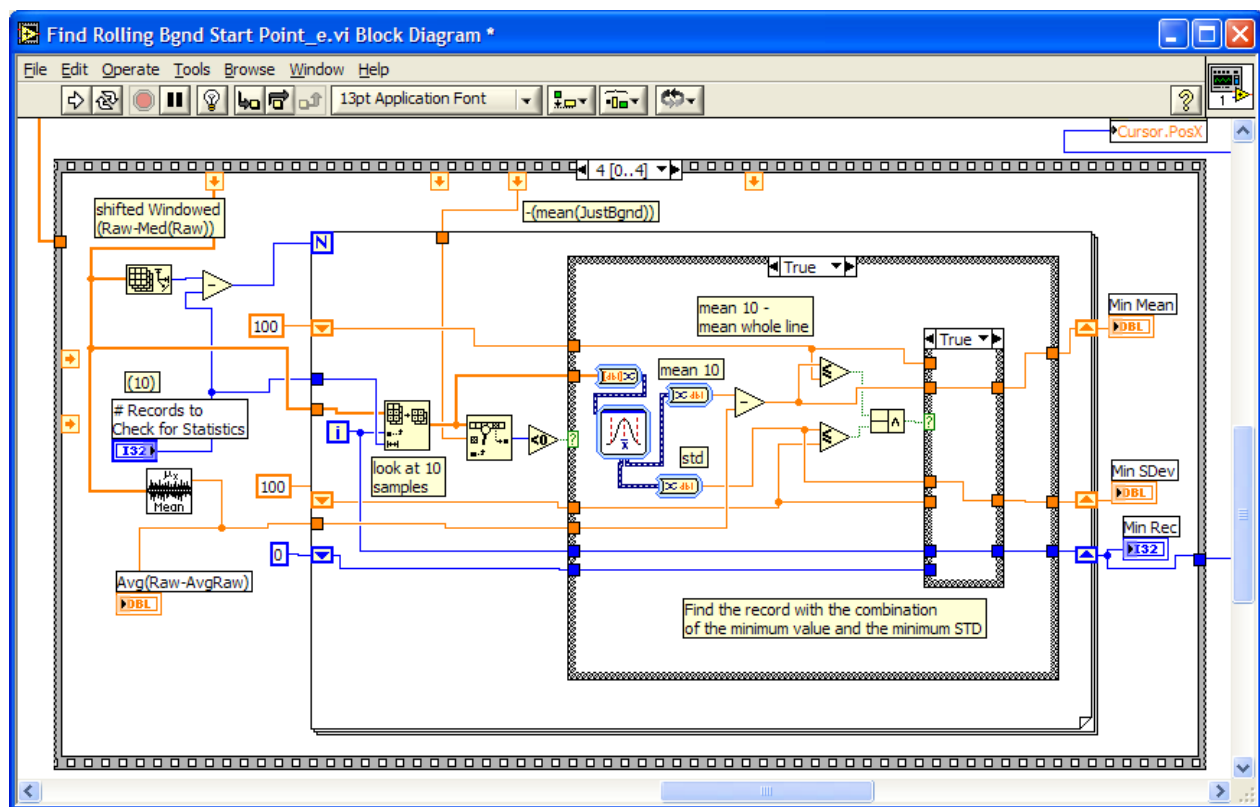
Figure A2.7. Screen shot of the process of finding the record with the minimum mean and standard deviation.

Function performed by "Build Recon GPS Array_b.vi"
 (Create Recon GPS Array button)
In the user input panel that appears when the **Find Background Subtraction** Start button is clicked:
1. Select a ".csv" file in the directory of the data you wish to create the reconstructed GPS arrays. The directory and file must have been previously created.
2. Specify the time difference in hours between the UTC time recorded in the system GPS files and the UTC time used to construct the reconstructed GPS in the ".csv" file. The ".csv" time is stored as HHMMSS.SS.

 Click **ACCEPT** button when selections have been made. The program will begin scanning the ".csv" file to determine gaps in the UTC and fill in the gaps with interpolated UTC, Northing and Easting values for the gaps.

The reconstructed GPS file is created from the stored GPS information on the GPS base and GPS rover. The reconstruction program is supplied by Leica, and uses the UTC time stamps on both the base and rover data sets to correlate the GPS values from the two units, at a particular UTC time. It then creates RTK latitudes and longitudes for the rover, for that UTC time.   The values are converted to Northing and Eastings with Geosoft Oasis montaj, and stored with the UTC in the **Reconst GPS File**. The stored GPS values are the ones stored locally on the GPS units flash memory cards, not the GPS values that are stored by the data acquisition system. The need for the use of the reconstructed GPS is described in the section entitled "Use of the Reconstructed GPS File in the waveform processing program".

The **Build Recon GPS Array** program begins by reading in the **Reconst GPS File** and placing the UTC, Easting and Northing information into an array. Each entry is assumed to be separated in time by the UTC increments of the GPS unit being used. The current program is hard coded for increments of every 50ms (Leica GPS used for USGS surveys).   If the increments are different, the program will have to be modified to accommodate this.

The **Reconst GPS File** currently being used has a header before the data. The header format is: Point_ID,Easting,Northing[CR][LF].   The program scanning in the data must jump past the header to get to the first UTC data. The header must be in the stated format for the jump to be calculated correctly. The data contained in the **Reconst GPS File** is ASCII, comma delimited, with [CR][LF] end of line terminators. An example of the beginning of a file, including the header, is shown here:

        Point_ID,Easting,Northing
        11275300,402778.766507382,4369576.03641152
        11275305,402778.783329934,4369576.04390899
        11275310,402778.801551336,4369576.04861388
        11275315,402778.817668661,4369576.0570452
        11275320,402778.83563179,4369576.06021164

The ASCII data cannot be read into the LabVIEW program using the **read from spreadsheet** function, which would be very fast. When this function is used, the precision of the digits to the right of the decimal point is lost. Instead, the data must be read in as a text file and converted

line by line to an array format. This is much slower, but preserves the data precision.   To speed things up, it is suggested that only the lines that have known GPS problems be placed in the **Reconst GPS File**. To find the lines that have problems, the **Find GPS Problems** function should have been run previously.   The lines with problems are in the arrays labeled: "MissingHeadGPS X", "MissingHeadGPS Y", "MissingHeadGPS Z", "BadGPS X", "BadGPS Y", and "BadGPS Z" in the **Site Specific Settings** configuration file. Lines with either missing headers or non-RTK_FX GPS values will need to be replaced with the reconstructed GPS values
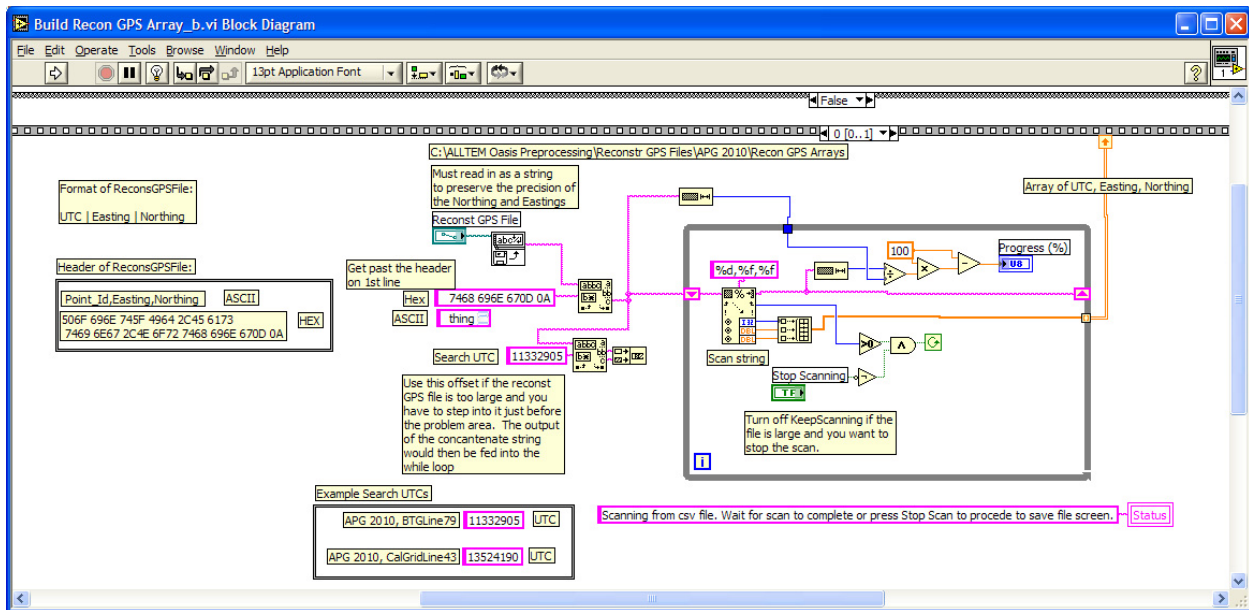

Figure A2.8. Screen shot of the process of the reading in and conversion of the **Recon GPS File**

Once the array has been filled, the process begins to find the places where there are gaps in the UTC values. Because the GPS updates positions 20 times per second, the regular interval is 50 ms between UTC values. Therefore, true gaps are 100 ms or greater.   The format of UTC is HHMMSS.SS, for example 11275305 is 11 hours, 27 min, 53.05 sec.

One difficulty in using successive differences to find gaps is that hours and minutes are modulo 60. Simple subtraction creates apparent gaps in the UTC values when the time rolls over after every minute :

       UTC Value
       11585990
       11585995 change = 5
       11590000 change = 4005
       11590005 change = 5

And on every hour transition:
       UTC Value
       11595990

11595995 change = 5
12000000 change = 404005
12000005 change = 5

These transitions have to be identified and handled so that they do not trigger the case that handles true gaps and cause errors when calculating interpolation values. If a true gap is detected, then the program first determines the length of the gap and then interpolates new UTC values (in 50 ms increments) to fill in the gap. Additionally, for each new UTC value, an interpolated Northing and Easting are calculated. These are put into an array (Fill-In Array). The interpolation is performed linearly from the last good Northing and Easting before the gap to the first ones after the gap. Because this is done linearly, the resultant interpolated Northing and Easting values will appear to be a zigzag, or stair-step, in the gap. The zigzag will be most accentuated if the gap occurred when the system was travelling on a diagonal between north and east. An additional array is formed to keep track of where the gaps were detected (**UTC Breaks**). This array holds the gap's starting UTC and the length of the gap.
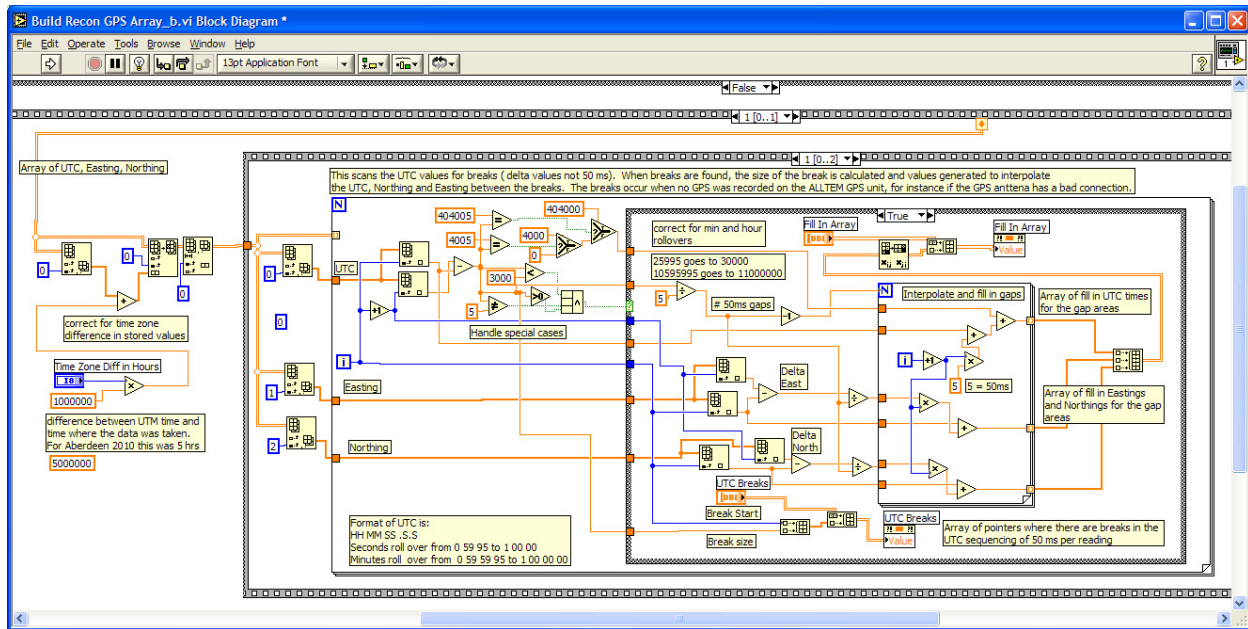

Figure A2.9. Screen shot of the process of finding gaps and interpolating between them.

The next step involves correcting the UTC time values to be in the same time zone as the data from the survey being processed. The user is given a field to enter the time difference (in hours) between UTC and the time zone that the data were taken in.

The **UTC Breaks Array** is used to determine where to splice the **Fill-In Array** values into the original **Recon GPS File Array**. This spliced array is named **Recon GPS Array**.

Finally, the **Recon GPS Array**, **Fill-In Array** and the **UTC Breaks Array** are saved into the **Site Specific Setting** configuration file that was passed into the program from the calling program.
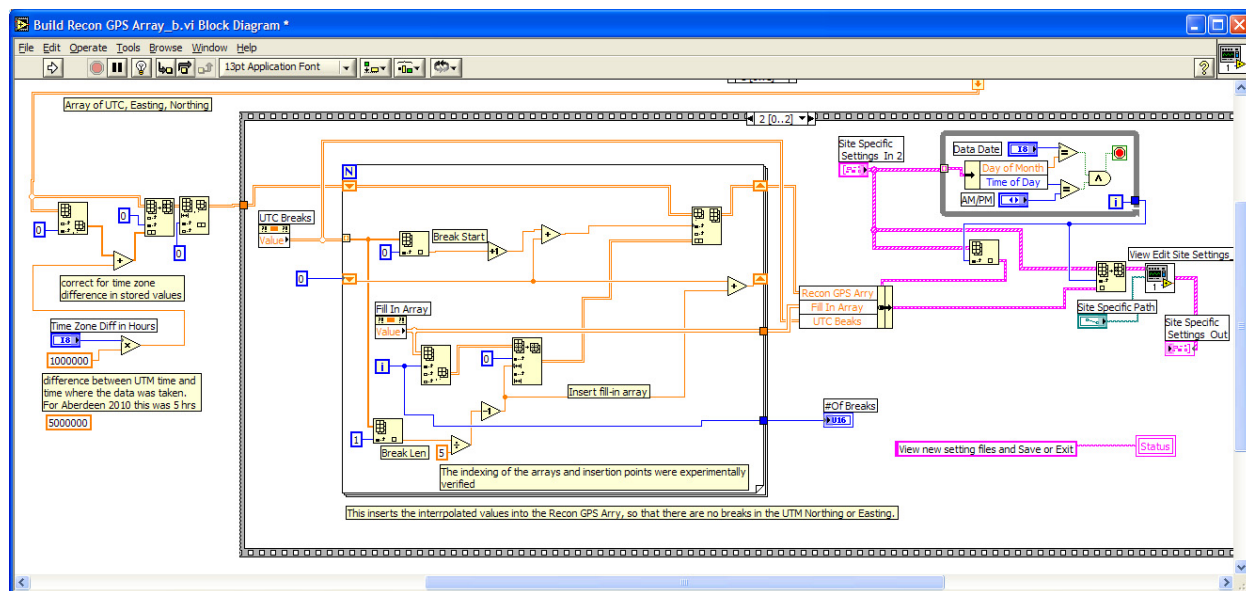

Figure A2.10. Screen shot of the process of splicing in of the **Fill in Array** values and construction of the **UTC Breaks Array**.

Use of the Reconstructed GPS file in the waveform processing program

Two conditions require the use of the reconstructed GPS file. The first occurs when there was a problem with the rover GPS unit that caused it to not receive any satellite data for some period during a survey. In this event, no GPS values are stored with the gathered waveforms. The headers with the waveforms for this period have no GPS data: UTC, latitudes, and longitudes. In order for the reconstructed GPS file to be used, there must be a unique UTC in the header of each waveform so that it can be matched with a UTC in the reconstructed GPS file. In this way the corresponding reconstructed GPS values can be inserted into the waveform header. To accomplish this, the Find Bad GPS process searches the waveform headers for missing GPS data. The waveform record numbers where errors occur are put into the MissingHeadGPS arrays in the **Site Specific Settings** configuration file. This process also interpolates the GPS millisecond timer values and record numbers, and the GPS mode number is set to "0" (not-RTK). This information is then used during the normal waveform processing of all lines to fill in the UTC values with interpolated UTC values in the header gaps.
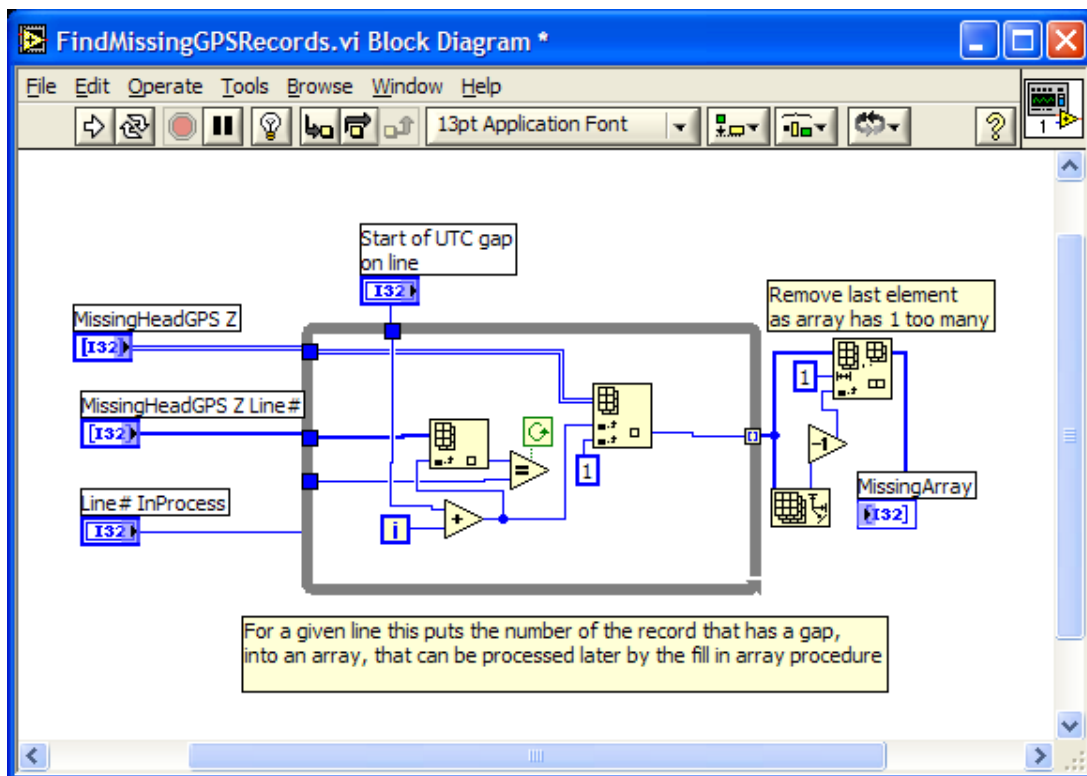

Figure A2.11. Screen shot of process to search MissingHeadGPS array to find missing GPS headers on a line.
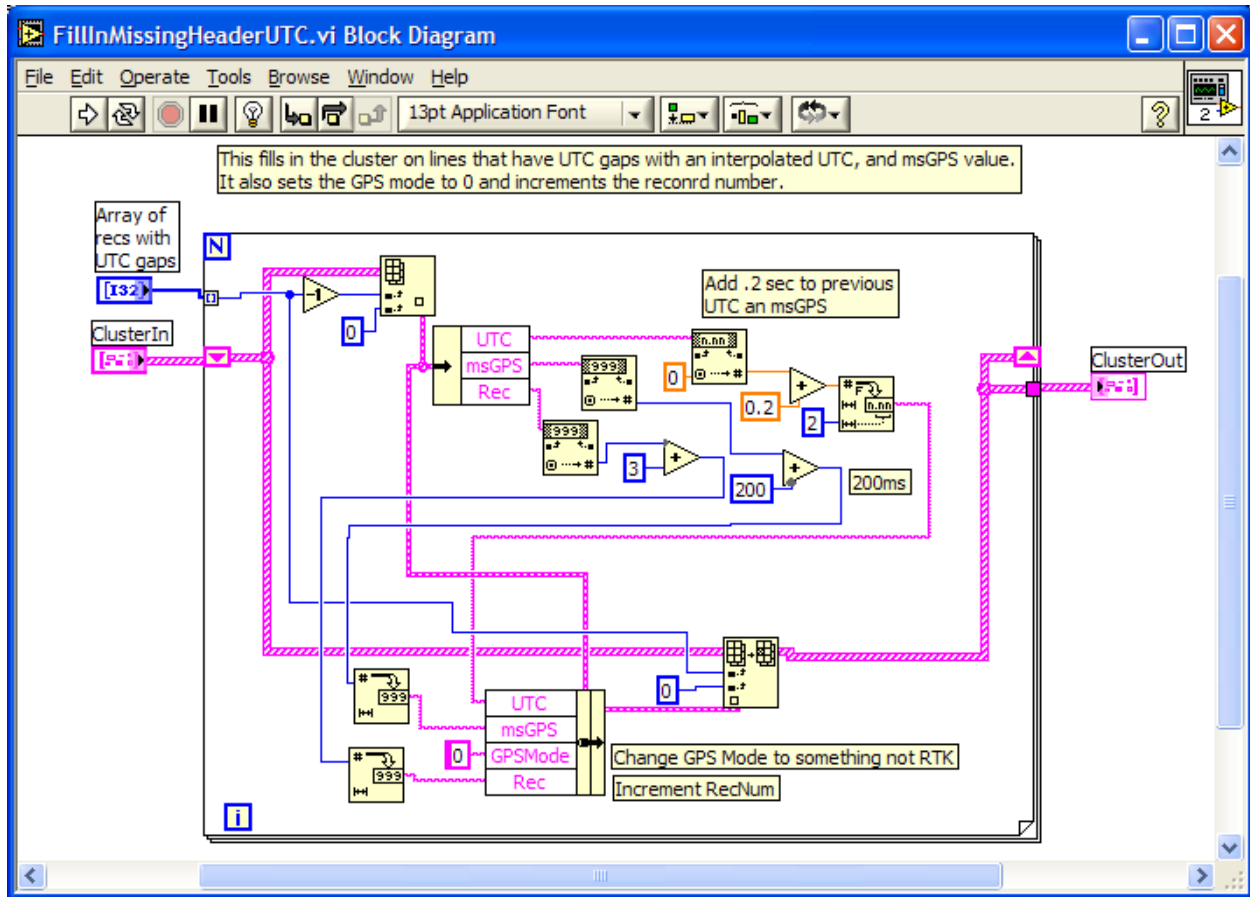
Figure A2.12. Screen shot of process to fill in the GPS header array (ClusterIn) with interpolated values.

The second case for using the reconstructed GPS files is to correct position data when the GPS mode on the rover went to something other than RTK_FX. This can occur if the satellite constellation precludes a RTK-fixed solution, or if there is some problem with the radio telemetry between the GPS base station and the rover GPS. In this case the information stored in the BadGPS arrays in the **Site Specific Setting** configuration files is used. The BadGPS array contains the lines that had non-RTK_FX GPS values. When one of these lines is being processed, a comparison search is made between the UTCs in the reconstructed GPS array and the UTC in the array having the waveform header information. When a match is found, the GPS Northing and Easting in the reconstructed GPS array are substituted for the corresponding values in the array having the waveform header information. This GPS information is then stored in the ".dat" or ".wfm" files.
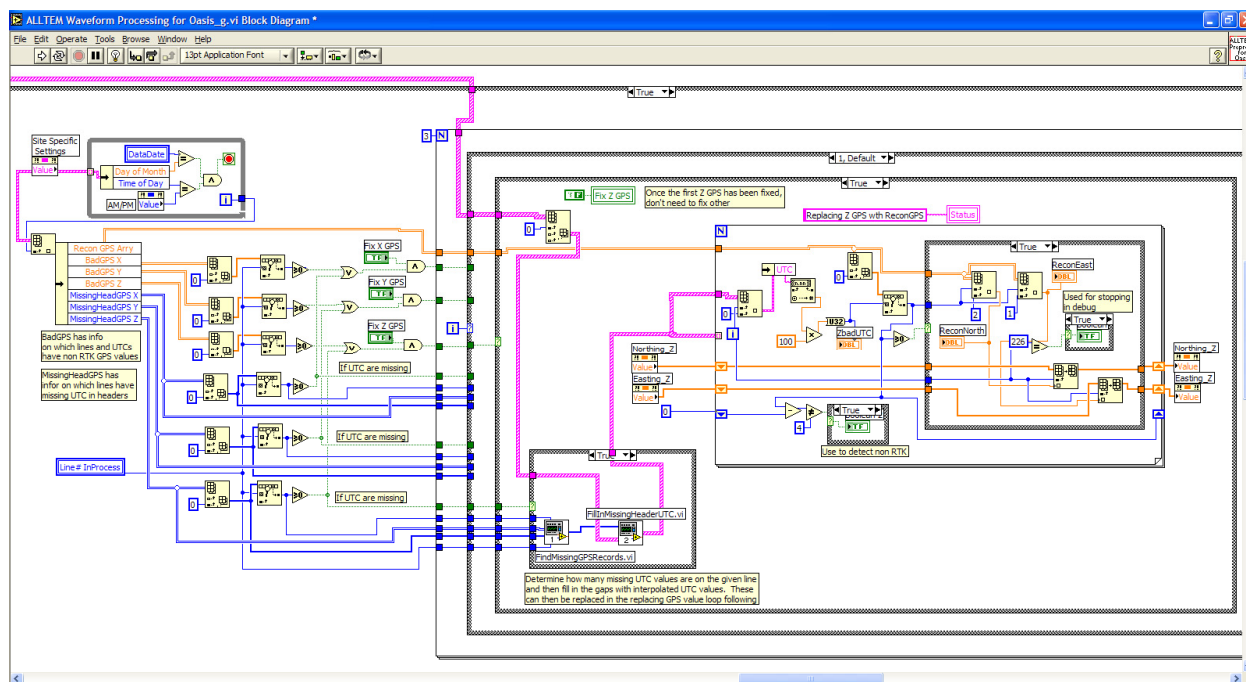
Figure A2.13. Screen shot of the process to identify and replace Northing and Easting values with the values from the reconstructed GPS array.